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STRUCTURES and ENVIRONMENT HANDBOOK

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Midwest Plan Service
STRUCTURES AND ENVIRONMENT HANDBOOK
MWPS-1
7th Edition, 1975

To our readers: This handbook is the seventh annual revision of a continuing program to bring together in one set of covers those facts, concepts, and relationships of importance to students, teachers, and practitioners in the field of farm structures. The first edition was a raw assemblage of publications from the MWPS, universities, trade associations, and the American Society of Agricultural Engineers. Subsequent editions have gradually increased the material included and upgraded the presentation.

You will find errors, and may notice omissions. Please help us and future users by reporting them to the Midwest Plan Service. Your suggestions—and draft copy—for useful additions are most welcome; the 1975-76 edition will be locked up about April 1, 1976.

Acknowledgments: A Work Committee of the MWPS supervised this revision: Dr. C. K. Spillman, Kansas State U, Chairman; Dr. C. O. Cramer, U of Wisconsin; Dr. J. O. Curtis, U of Illinois; Dr. M. A. Hellickson, S. Dakota State U; Dr. D. W. Mangold, Iowa State U; Dr. N. F. Meador, U of Missouri; Dr. G. L. Pratt, North Dakota State U; Dr. D. P. Stombaugh, Ohio State U.

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A companion book, Professional Design, MWPS-17, was started in 1974. The 1975 edition will be about 165 pages, and provides theory and development material for professional engineering courses.

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CHAPTER 112 WOOD TERMINOLOGY AND CHARACTERISTICS

Wood is a very versatile and variable building material. Its many characteristics differ greatly with such things as species, moisture content, and quality of the wood. An understanding of these various characteristics and a knowledge of how the different species rate on a given characteristic is essential to choosing a species or quality of wood for a particular end use.

Wood Terminology

There are a number of unique terms that are commonly used in describing or discussing wood. It is helpful to have an understanding of these terms before attempting to learn about wood characteristics.

Hardwoods and Softwoods

All native species are divided into two classes—hardwoods and softwoods. In general hardwoods have broad leaves and are deciduous (shed their leaves each season). On the other hand, softwoods are conifers, and have scalelike leaves as in cedars or needlelike leaves as in pines. Thus, the terms "hardwood" and "softwood" have no direct application to the hardness and softness of the wood.

Heartwood and Sapwood

Sapwood is located around the outer portion of a log, functions in sap conduction, and consists of living cells. It varies in thickness with tree age and species, but it is commonly 1-1/2 to 2 inches thick.

Heartwood is inactive cells in the central portion of a log. The cavities of heartwood may contain various deposits that give it a darker color and usually make it more durable. Heartwood and sapwood of a given species are considered to be about equal in weight and strength.

Growth Rings

In many species there is sufficient difference between wood formed early and that formed late in the growing season to produce well-marked annual growth rings.

Springwood

Springwood is the inner part of the growth ring that is formed first in the growing season. It is characterized by cells having relatively large cavities and thin walls.

Summerwood

Summerwood is the outer part of the growth ring that is formed later in the season. Its cells have smaller cavities and thicker walls. When growth rings are prominent, as in southern yellow pine, springwood differs markedly from summerwood in physical properties. Springwood is lighter in weight, softer, and weaker than summerwood.

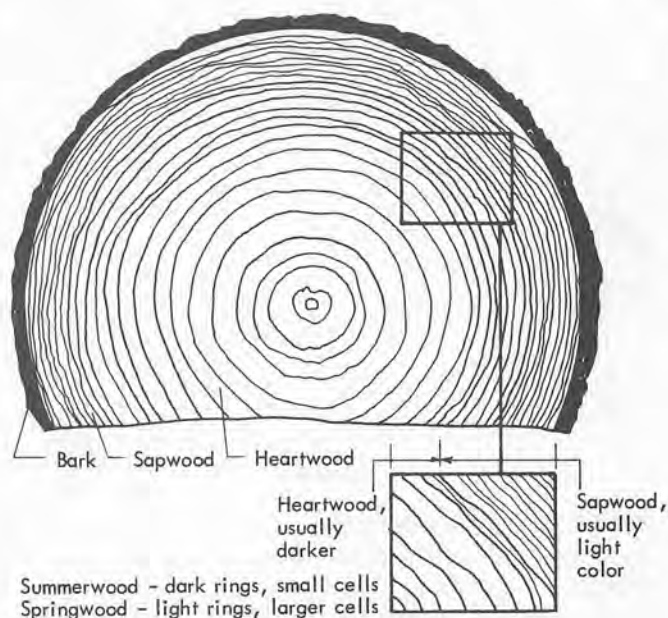


Fig 112-1. Tree growth rings.

Direction

Many characteristics of wood vary with direction. The three common directions are:

- Longitudinal—parallel to the long axis of the log or parallel to the grain of the wood
- Radial—perpendicular to the growth rings
- Tangential—tangent to the growth rings

Lumber may be cut from a log in two different ways (Fig 112-2). One is tangent to the growth rings and produces **plainsawed, flat-grained or slash-grained** lumber. The annual rings generally form angles of less than 45° with the wide face of the board.

The other way is radial to the growth rings and produces **quartersawed, edge-grained or vertical-grained** lumber. The annual rings generally form angles of more than 45° with the wide face of the board.

Wood Characteristics—Table 112-1.

Hardness

Hardness is the property that makes a surface difficult to dent, scratch, mar, or cut. The harder the wood is the better it resists wear, the less it crushes under the load, and the better it can be polished. But, harder wood is more difficult to cut with tools, harder to nail, and the more liable to split in nailing.

Weight, Density, Specific Gravity

Weight is measured in pounds; density is in pounds per unit volume, or pounds per cubic foot. Density is a reliable indicator of the strength of dry wood, when the degree of dryness and actual

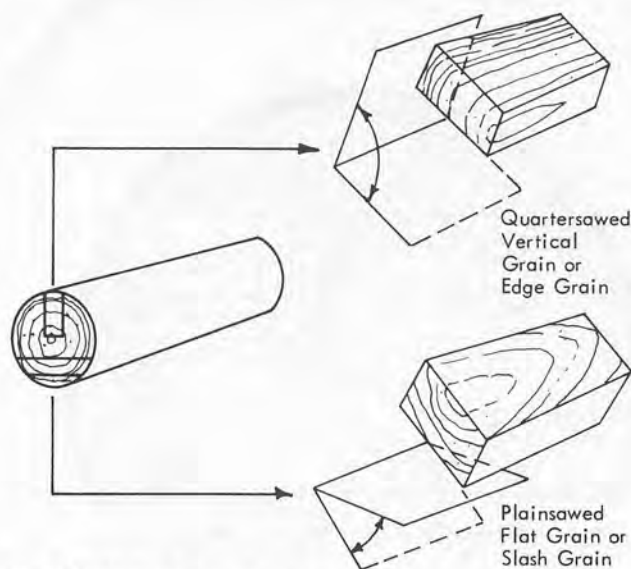


Fig 112-2. Cutting lumber from a log.

sizes are the same. Since the density of a piece of wood is a combination of the weight of the wood fibers and the water they contain, densities are commonly expressed for either green (over 30% moisture) or air-dried (about 12%) wood. The green density is that of the living tree.

Specific gravity (S.G.) is the density of a material compared to water. An S.G. less than one

indicates a material lighter than water; it will float.

Ease of Working

Wood that is easy to work makes for a better appearance on the job and requires less labor in fabrication. Different woods vary greatly in their workability and machinability characteristics. While no precise test has been devised for rating woods on ease of working, a general one is given in Table 112-1. It is based on hardness, texture, and character of the surface that may be obtained. Class A woods have soft, uniform texture and finish to smooth surfaces.

Paint Holding Ability

Woods vary greatly in their paint holding ability. Paint holds better on edge-grain than it does on flat-grain. Knots in both the white and yellow pines do not retain paint as well as the sound knots of the cedars, hemlocks, white fir or western larch. The bark side of a flat-grained board is more satisfactory to paint than the pith side.

Nail Holding Power

Nail holding power is closely related to the density or specific gravity of the wood and to its splitting tendencies. Generally, the denser and harder the wood, if unsplit, the greater its holding power.

Table 112-1. Classification of Wood according to characteristics and properties.

A, B, C and D are relative ratings of the species for each characteristic, or property. Rating A is high or desirable.

KIND OF WOOD	WORKING AND BEHAVIOR CHARACTERISTICS							STRENGTH PROPERTIES		
	Hardness	Weight Air Dry	Ease of Working	Paint Holding	Nail Holding	Heartwood Decay Resistance	Gluing Characteristics	Bending	Stiffness	Toughness
(Softwoods)										
Cedar, Inland Red	A	A	B	A	C	A	B	C	C	B
Cedar, Western Red	C	C	A	A	C	A	A	C	C	C
Fir, Douglas	B	B	C	C	B	B	B	A	A	B
Fir, White	C	C	B	B	C	C	A	B	B	C
Hemlock, Western	B	B	B	B	B	C	B	B	A	B
Larch, Western	A	A	C	C	A	B	B	A	A	B
Pine, Western White	C	B	A	A	A	B	B	B	B	B
Pine, Lodge Pole	C	C	A	A	B	B	B	B	B	B
Pine, Ponderosa	C	B	A	B	B	B	B	C	C	C
Pine, Southern Yellow	A	A	C	C	A	B	B	A	A	B
Pine, Sugar	C	C	A	A	A	B	B	C	C	C
Redwood	B	B	B	A	B	A	A	B	B	B
Spruce, Englemanns	C	C	B	B	C	C	A	C	C	C
Spruce, Sitka	C	B	B	B	C	C	A	B	A	B
Tamarack	B	A	C	B	B	B	B	B	B	B
(Hardwoods)										
Ash, White	A	A	C	C	A	C	C	A	A	A
Birch, Yellow	A	A	C	B	A	C	D	A	A	A
Cottonwood	C	B	B	B	C	C	A	C	B	B
Elm, Rock	A	A	C	C	B	B	B	A	A	A
Hickory, True	A	A	C	C	A	C	D	A	A	A
Maple, Hard	A	A	C	B	A	C	D	A	A	A
Oak, Red or White	A	A	C	C	A	A	C	A	A	A
Walnut	A	A	B	C	B	A	C	A	A	A

Decay Resistance

Wood that is kept either continuously dry or continuously wet is not subject to decay. But, wood at 21%-24% moisture content for appreciable periods is subject to decay. Untreated sapwood of nearly all species has low decay resistance. The heartwood of some species has natural decay resistance.

Gluing Characteristics

A number of factors affect the gluing characteristics of wood. In general heavy woods are more difficult to glue than lightweight woods, hardwoods are more difficult to glue than softwoods, and heartwood is more difficult than sapwood.

Bending Strength

The strength of a structural-size wooden member depends on the number, size and type of defects and on the species. The basic strength of wood varies greatly with species. Relative strengths in bending are given for a number of species in Table 112-1. The bending strength measures the load-carrying capacity of such members as rafters, girders, and floor joists. Class A softwoods as given in the table dominate the structural field. Class B softwoods are used occasionally in heavy construction, and extensively in light construction.

For a given species and member length, bending strength is proportional to the square of the depth, but is directly proportional to width:

Full size, on edge:	2 x 4	4 x 4	2 x 8
Relative strength:	1	2	4

Bending strength is inversely proportional to the square of the span for uniformly distributed loads:

Span	10'	20'
Relative strength	1	1/4

Stiffness

Stiffness measures resistance to sag or deflection under load. It is an important characteristic for studs, joists, rafters, beams, shelving, ladder rails, etc. *It depends on the cross section shape of its member and a property of wood called modulus of elasticity.*

The relative stiffness of the more common species is indicated in Table 112-1. Softwoods in classes A and B are used where stiffness is the most important requirement. The class A woods are usually heavier and harder than the class B woods. Softwoods are often preferred over hardwood because of their lighter weight.

For a given species, stiffness is proportional to member width and to the cube of member depth:

Full size, on edge	2 x 4	4 x 4	2 x 8
Relative stiffness	1	2	8

Stiffness is inversely proportional to the cube of the span for a concentrated load:

Span	10'	20'
Relative stiffness	1	1/8

Toughness

Toughness indicates wood's ability to absorb shock or impact loads. Toughness is needed for

implement or tool handles, and ladders; hardwoods are commonly selected.

Wood Defects

Some natural, drying, and milling characteristics result in defects in manufactured lumber. Some are illustrated in Fig 112-3.

Cross grain—grain not parallel to board length. Check—lengthwise separation of wood across the annual growth rings. It results from differential shrinkage in radial and tangential directions.

Decay—disintegration of wood by fungi.

Holes—holes in wood from any cause.

Knot—embedded branch exposed during manufacture.

Pitch pocket—an opening between the annual rings caused by pitch accumulation.

Stain—discoloration of wood from natural color.

Wane—bark, or a lack of wood on the corner of a piece from any cause.

Warp—variation from straightness in a piece.

Moisture Content and Shrinkage

Moisture content (% mc) in wood is the weight of water in the wood divided by the weight of the wood itself.

% mc =

$$\frac{\text{weight green wood} - \text{oven dry weight}}{\text{oven dry weight}} \times 100$$

Green wood has "free water" in cell cavities and "absorbed water" in cell walls. As green wood dries the cell walls remain saturated until the free water has been evaporated. The point at which cell walls begin to lose moisture is the "fiber saturation point," and is about 30% mc for most species (Fig 112-4).

Moisture content variations above the fiber saturation point (30% mc) do not affect the size or strength of wood. But as wood dries below fiber saturation and moisture begins to move from the cell walls, shrinkage begins and strength increases. The amount of shrinkage that occurs varies in the radial, tangential, and longitudinal directions (Table 112-2 and Fig 112-5).

If lumber is installed at about the % mc it will attain in service, only minor dimensional changes will occur.

Table 112-2. Shrinkage of woods as % of green dimensions.

Species	Dried to 20% mc		Dried to 6% mc	
	% Radial	% Tangential	% Radial	% Tangential
Douglas Fir	1.7	2.6	4.0	6.2
Western Hemlock	1.4	2.6	3.4	6.3
Ponderosa Pine	1.3	2.1	3.1	5.0
Redwood	.9	1.5	2.1	3.5
Western Red Cedar	.8	1.7	1.9	4.0
Southern Yellow Pine	1.6	2.5	3.8	5.9

Total longitudinal shrinkage is 0.1% - 0.3% of green size.

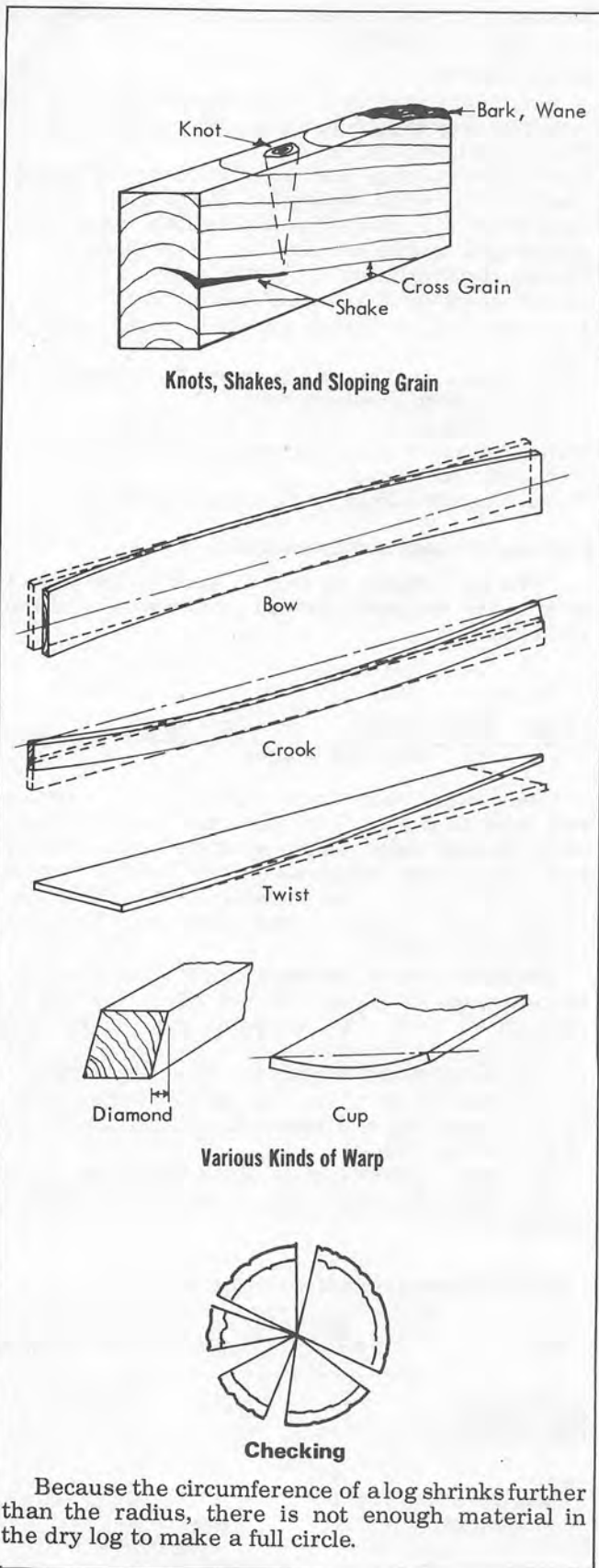


Fig 112-3. Defects in wood.

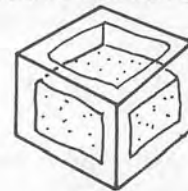
Typical Lumber Shrinkage Problem

Shrinkages of house siding depend on initial moisture control, species, and climate. Excessive shrinkage breaks the paint seal at every board. If the siding is at 20% mc, and due to climate will reach equilibrium at 6% mc (emc) through part of each year, which species shrinks least? Compare 8" vertical grain siding of 4 species;

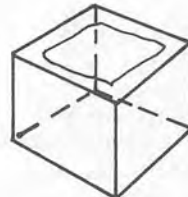
Wood	Radial Green to 6%	Shrinkage Green to 20%	Differ- ence	Width of Board	Shrinkage
Western Red Cedar	1.9%	.8%	1.1%	8"	0.088"
Redwood	2.1	.9	1.2	8	0.096"
Douglas Fir	4.0	1.7	2.3	8	0.184"
Southern Yellow Pine	3.8	1.6	2.2	8	0.176"

Western red cedar and redwood shrink and swell less than Douglas fir or southern pine.

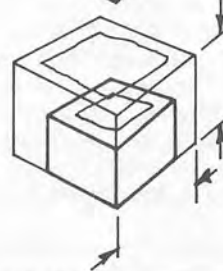
Moisture In a Cell of Wood



Above 30% mc.
Free water
within cells.



About 30% mc.
At fiber saturation.
Free water gone.
Absorbed water in
cell walls.



Below 30% mc.
Cells shrink as
absorbed water
leaves cell walls.

Fig 112-4. Moisture in wood cells.

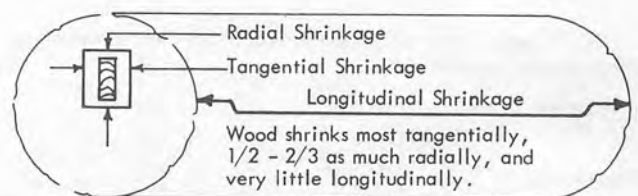


Fig 112-5. Relative shrinkage in three directions.

CHAPTER 113 LUMBER FOR FARM BUILDING CONSTRUCTION*

Lumber for farm building construction is available in a number of species, strengths, appearance qualities, moisture contents, prices, etc. The objective when choosing or specifying lumber is to obtain a satisfactory quality at the lowest possible cost.

The lumber used in farm buildings may be grouped into two major categories, ungraded or native lumber and commercial lumber. Native lumber comes directly from local saw mills or is cut from the farmers' own logs. Commercial lumber is in commercial trade channels and is available in standard strength and appearance grades.

Ungraded or Native Lumber

Ungraded or native lumber is widely used in farm buildings in areas where timber is grown. Since it is ungraded, it includes some strong pieces, many pieces of adequate strength for light frame construction, and some pieces that are weak. It is a satisfactory material, especially if sorted to select the stronger pieces for members such as joists and rafters. The weaker pieces, then, may be used for plates, sills, braces, studs in light buildings, etc. Native lumber is also recommended for sub-flooring, pens and partitions, and other non-structural uses. When the stronger pieces are identified and used where strength is required, native lumber can normally be substituted size-for-size for the commercial lumber normally shown on building plans.

The strength of lumber depends primarily on species, moisture content, and number and size of strength reducing defects. Some species of lumber are naturally stronger than others. The relative clear strengths of some common woods are shown to identify the strong and weak species.

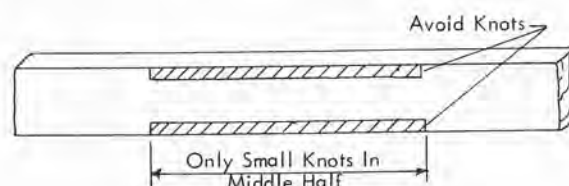
Table 113-1. Relative strength of clear lumber.

Species	Relative Strength in Bending
Cottonwood	50%
Douglas-fir: coast type	100%
Elm: American	73%
Hemlock: Western	86%
Hickory	127%
Maple: hard	100%
Oak: red and white	93%
Pine: southern yellow	100%
Spruce: Engelman	50%
Yellow-poplar	66%

In general, as lumber dries it becomes stronger. Since native lumber may be used before it is thoroughly dry, it does not have its full strength at the time of fabrication. It will dry fairly rapidly, though, while in place in the structure. Use ring-shank nails and tighten bolts after the lumber has dried.

*Chapter prepared by Dr. J.O. Curtis, University of Illinois.

The user may visually inspect and sort lumber to select the stronger pieces. Obviously those pieces that are nearly clear or that have only small knots are stronger. Select joists and rafters from pieces that have only small knots (less than 1/3 width of piece) in the middle 1/2 length. Knots may be up to one-half of the width of the piece if located elsewhere. Discard pieces that show rot or that are noticeably undersize.



Commercial Lumber

Most commercial lumber in farm buildings is softwood lumber and is graded in accordance with the American Softwood Lumber Standard. This standard establishes a common basis for uniform, industry wide inspection and grade marking practices for each piece of lumber produced and sold under its provisions. It also provides a standardized working basis for the coordination of the grades of various species of softwood lumber and for the preparation of grading rules applicable to each species. Lumber conforming to the basic minimum size and grade provisions of the American Lumber Standard is graded under the rules of the various regional associations that have been approved by the Board of Review of the American Lumber Standards Committee.

Lumber is produced for various end uses, in a variety of sizes and moisture contents, and in several manufacturing classifications. Lumber is classified according to end use as yard lumber, structural lumber, or factory and shop lumber.

- **Yard lumber** is intended for ordinary construction and general building purposes and is that commonly available in local lumber yards.
- **Structural lumber** is framing lumber that is used where a given level of working stress or strength is required. Some structural lumber is also available from local lumber yards.
- **Factory and shop lumber** is intended for remanufacturing purposes.

Lumber is classified according to nominal size as **boards**, **dimension**, and **timbers**. Table 113-2.

- **Boards** are less than 2" in nominal thickness and 2" or more in nominal width.
- **Dimension** lumber is from 2" to, but not including, 5" in nominal thickness and 2" or more in nominal width.
- **Timbers** are 5" nominal or more in least dimension.

Table 113-2. Nominal and Minimum-dressed sizes of boards, dimension, and timbers.

(The thicknesses apply to all widths and all widths to all thicknesses.)

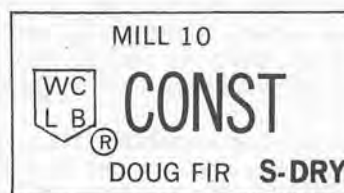
ITEM	Thicknesses		Face Widths	
	Nominal	Dressed Dry	Nominal	Dressed Dry
Boards	1	3/4 in.	2	1 1/2 in.
	1 1/4	1	3	2 1/2
	1 1/2	1 1/4	4	3 1/2
			5	4 1/2
			6	5 1/2
			7	6 1/2
			8	7 1/4
			9	8 1/4
			10	9 1/4
			11	10 1/4
			12	11 1/4
			14	13 1/4
			16	15 1/4
Dimension	2	1 1/2	2	1 1/2
	2 1/2	2	3	2 1/2
	3	2 1/2	4	3 1/2
	3 1/2	3	5	4 1/2
	4	3 1/2	6	5 1/2
	4 1/2	4	8	7 1/4
			10	9 1/4
Timbers			12	11 1/4
	5 and thicker (Dressed green)	1/2 off	5 and wider	1/2 off

Lumber is surfaced either dry or green. Dry lumber has been seasoned or dried to a moisture content of 19% or less. Green lumber has a moisture content over 19%. Lumber is surfaced green, at a slightly larger size than when surfaced dry. The objective is lumber at the same size in service regardless of whether it was surfaced dry or green.

There are three regional associations that grade most of the softwood lumber: the Southern Pine Inspection Bureau (SPIB), the West Coast Lumber Inspection Bureau (WCLB), and the Western Wood Products Association (WWPA). Even though the grading rules of these three associations conform to the American Lumber Standard, there are variations in the names assigned to comparable grades of lumber.

Typical grades of lumber used in farm construction are summarized in Table 113-3. Suggested uses for each grade are also given. Since the cost of lumber normally varies directly with the grade, select the lowest grade that is satisfactory for the intended use.

Most yard and structural lumber is grade stamped to help the consumer identify a given piece's grade. In addition to the grade, the stamp normally indicates the grading association, the mill that manufactured the lumber, the species, and the moisture content at which the lumber was surfaced. The following are typical grade stamps of two different grading associations:



WCLB = the grading association.
MILL 10 = the mill code number.
CONST = the lumber grade.
DOUG FIR = the lumber species.
S-DRY = lumber surfaced at 19% mc or less.



S-GRN = lumber surfaced green.
DOUG FIR-L = the species is mixed Douglas fir and larch.

WWP = the grading association.
12 = the mill code number.
SEL STR = the lumber grade.

The strength and stiffness values of lumber are important for many end uses. Strength values are tabulated for some lumber grades in Chapter 131.

American Softwood Lumber Standard

The new standard became effective on July 1, 1970. Lumber is classified according to extent of manufacture.

- **Rough lumber** has not been dressed (surfaced) but has been sawed, edged, and trimmed at least to saw marks showing in the wood on the four longitudinal surfaces of each piece for its overall length.
- **Dressed (surfaced) lumber** has been planed to smooth surfaces and uniform size on one side (SIS), two sides (S2S), one edge (S1E), two edges (S2E), or combination of sides and edges (S1S1E, S1S2E, S2S1E, S4S).
- **Worked lumber** has been dressed, and has been matched, shiplapped, or patterned.
- **Matched lumber** has been worked to a tongue on one edge of each piece and a groove on the opposite edge for close tongue-and-groove joints by fitting two pieces together; when end-matched, the tongue and groove are also worked in the ends.
- **Shiplapped lumber** has been worked or rabbeted on both edges of each piece for a close lapped joint by fitting two pieces together.
- **Patterned lumber** is further worked to a pattern or molded form.

Table 113-3. Grades of lumber.

Classification	Grades	Description or Use
Dimension 2" to 5" thick 2" or more wide	Structural Light Framing (2"-4" thick, 2"-4" wide)	• For engineered use where higher strength is needed. • Use where high strength and stiffness and good appearance are needed. • Use about the same as SEL STR, a little lower in quality. • Recommended for most general construction uses. • Use for general construction where appearance is not a factor.
	Select Structural	
	No. 1	
	No. 2	• Provides good appearance where high strength and high appearance are not needed. • Recommended and widely used for general framing purposes. • About same uses as CONSTRUCTION but a little lower in quality. • Used for studding, blocking, plates, etc. where economy and good strength are desired. • Suitable for crating, bracing and temporary construction.
	No. 3	
	Light Framing (2"-4" thick, 2"-4" wide)	
	Construction	• Only one grade; suitable for all stud uses. • For engineering applications.
	Standard	
	Utility	
	Economy	• Use where high strength and stiffness and good appearance are needed. • Use about same as SEL STR; a little lower quality. • Recommended for most general construction use. • For use in general construction where appearance is not a factor. • Use exposed in housing and light construction for high strength and finest appearance.
	Studs (2"-4" thick, 2"-4" wide)	
	Stud	
	Structural Joists & Planks (2"-4" thick, 6" & wider)	• Use where superior strength and good appearance are needed. • Similar uses to SEL STR; a little lower in quality. • Recommended for general construction. • Use for rough general construction.
	Select Structural	
	No. 1	
Timbers 5" or more in least dimension	No. 2	• Graded for suitability for use in construction. • Use in housing and light construction for exposed paneling, shelving, etc. • Use for subfloors, roof sheathing, etc. • Used about the same as #2 but a little lower in quality. • Combines usefulness and low cost for general construction purposes. • Use for low grade sheathing, crating and bracing.
	No. 3	
	Appearance Framing (2"-4" thick, 2" & wider)	
	A	
	Select Structural	
Boards up to 1½" thick, 2" or more wide	No. 1	• Graded on basis of appearance. • Nearly clear with only minor defects; suitable for natural finish. • More and larger defects than B & BTR but suitable for paint finish. • A little lower in quality than C but still suitable for paint finish.
	No. 2	
	No. 3	
	SEL MER or 1	
	CONST 2 STD 3	
Finish or Selects up to 1½" thick, 2" or more wide	UTIL 4	
	ECON 5	
	B & BTR	
	C	
	D	

CHAPTER 114 PLYWOOD*

The number of species and manufacturing variations used in plywood has increased considerably in recent years. Design, selection, and use are therefore more complex—specified or needed grades may not be stocked locally.

Manufacture

Plywood is manufactured with a number of plies or veneers (thin sheets of wood). Some plywood is now made with an even number of plies. Softwood veneer for panels used in agriculture is usually "rotary peeled" rather than sliced or sawn.

Peeler logs are cut into "blocks" usually about 8½' long. In a giant lathe, the blocks are rotated against a long knife that peels the wood off in a long, continuous, thin veneer. The veneer is cut to desired widths and dried to about 2%-5% moisture content. After careful grading, the veneer goes to the glue spreaders where the plywood panel is laid up.

The plywood then is cured, usually in a hydraulic press where both heat and pressure cure the glue in minutes. Panels are trimmed to size, and some grades are sanded. Plywood that conforms with U.S. Product Standard PS 1 carries a grade-trademark on every panel that permits easy identification.

Type

Plywood type, Interior or Exterior, depends on the resistance of the panels to moisture.

Some allowable stresses vary with the type of panel, whether Interior or Exterior. Shear strength, however, varies with the kind of glue used.

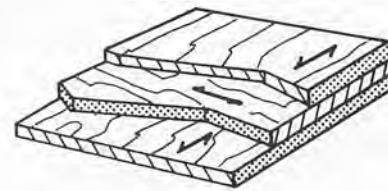
Exterior type plywood has superior resistance to moisture and weather. It is made with waterproof glue and has no veneer grade below C. Plywood with some D veneers is marketed as "Interior plywood with exterior glue," or "Interior plywood with intermediate glue."

Interior type

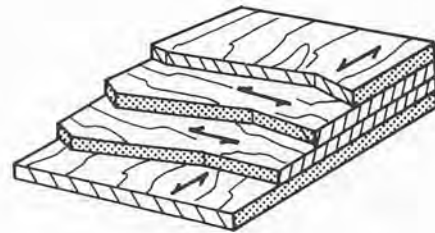
Interior type plywood is used where its equilibrium moisture content will not continuously or repeatedly exceed 18% or it is not exposed to the weather. Interior type plywood with exterior glue is used for sheathing where long construction periods are expected, and for some protected exposures where a high moisture level might some time be reached. Panels with an "intermediate glueline" pass more restrictive testing than an interior glueline, but do not have the durability of an exterior glue.

Exterior type

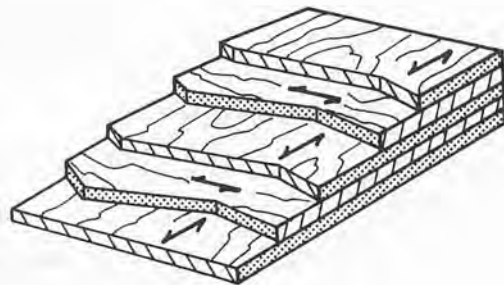
Plywood to be exposed to the weather or moisture contents continuously or repeatedly above 18% should be Exterior type.



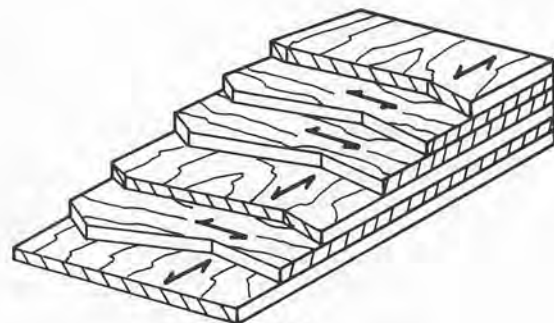
3 - Ply



4 - Ply



5 - Ply



6 - Ply

↔ Face Grain Direction

Fig 114-1 Typical 3- to 6-ply panels.

*Chapter prepared from publications of the American Plywood Association.

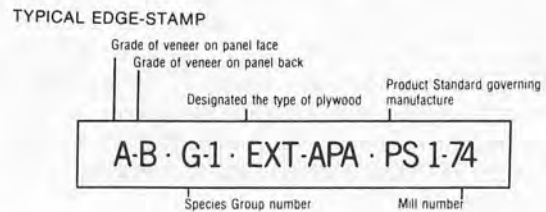
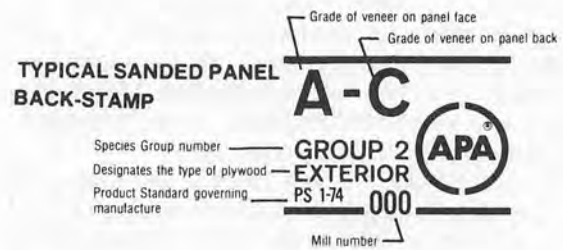
Veneer Grades

- N and A**—Highest grade level. No knots, restricted patches. Use N for a natural finish or paintable surface.
- B**—Solid surface. Small round knots. Patches and round plugs are allowed. Most common use is in Plyform, for concrete forms.
- C**—Special improved C grade used in Plugged UNDERLAYMENT.
- C**—Small knots, knotholes, patches. Lowest grade allowed in Exterior type plywood. For sheathing faces and inner plies in Exterior panels.
- D**—Larger knots, knotholes, some limited white pocket in sheathing grades. For inner plies and backs in Interior panels.

Wood Species

Woods for plywood are classified into 5 groups based on strength properties. Design stresses for a group are determined from clear wood specimens. Design stresses are published for Groups 1-4. All woods within a group are assigned the same working stress.

The group classification of a plywood panel is usually determined by the face and back veneer with the inner veneers allowed to be of a different group. Certain grades such as MARINE and the STRUCTURAL I have all plies of Group 1 species.



TYPICAL UNSANDED PANEL BACK-STAMP

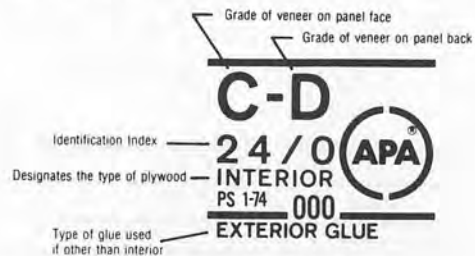


Fig 114-2. APA grade-trademarks.

Table 114-2. Classification of major species.

Group 1	Group 2		Group 3	Group 4	Group 5 ^a
Beech, American	Cedar, Port Orford	Maple, Black	Alder, Red	Aspen	Basswood
Birch: Sweet, Yellow	Cypress	Pine: Pond, Red, Virginia, Western White	Birch, Paper	Catino	Fir, Balsam
Douglas Fir 1 ^b	Douglas Fir 2 ^b		Cedar, Alaska	Cedar: Incense, Western Red	Poplar, Balsam
Larch, Western	Fir: California Red, Grand, Noble, Pacific Silver, White	Spruce: Red, Sitka	Fir, Subalpine	Cottonwood	
Maple, Sugar	Hemlock, Western	Tamarack	Hemlock, Eastern	Pine: Eastern White, Sugar	
Pine: Caribbean, Ocote, Loblolly, Longleaf, Shortleaf, Slash	Laan	Yellow-poplar	Maple, Bigleaf		
Tanoak			Pine: Jack, Lodgepole, Ponderosa, Spruce		
			Redwood		
			Spruce: Black, Engelmann, White		

^a Design stresses for Group 5 not assigned

^b Douglas fir No. 2 is from Nevada, Utah, Colorado, Arizona and New Mexico. Douglas fir No. 1 is from states farther west.

CHAPTER 115 NAILS*

The following discussion outlines the effects of various factors on the strength of nailed joints. It is included not as part of a design procedure, but as part of understanding the properties of wood.

Withdrawal Resistance

For bright, common wire nails driven into the side grain of seasoned wood that will remain dry, or unseasoned wood that will remain wet, the allowable withdrawal load is given by the formula:

$$p = 1390G^{5/2}D \quad \text{Eq 115-1}$$

p , the allowable load (1/6 the ultimate load) per lineal inch of penetration in the member holding the nail point; G , the specific gravity of the wood, oven-dry weight and volume; and D , the diameter of the nail in inches. Note: the allowable loads in Table 134-3 are approximately $= 1390G^{5/2}D$.

Dense, heavy woods generally have greater nail-holding power, but the less dense species do not split as readily and increasing the diameter, length, and number of the nails compensates for the wood's lower holding power.

Nails driven into green wood and pulled before any seasoning usually have the same withdrawal resistance as nails driven into seasoned wood and pulled soon after driving. However, common nails driven into green wood that seasons, or into seasoned wood subjected to cycles of wetting and drying, lose much of their withdrawal resistance. Even in seasoned wood not subjected to appreciable moisture content changes, the withdrawal resistance of nails may diminish with time.

Factors that affect withdrawal resistance

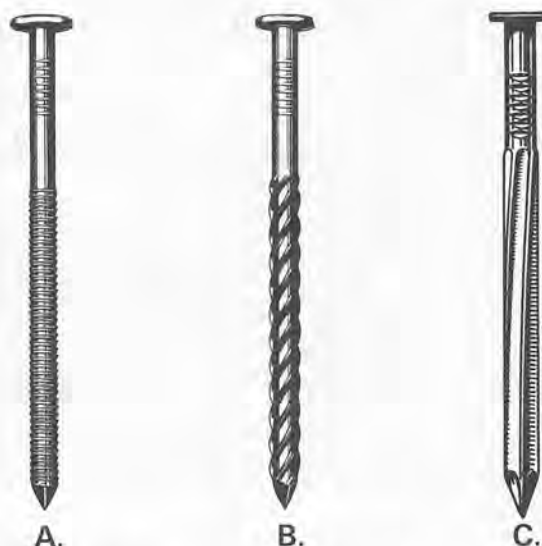
"Cement coating," properly applied, may double the resistance of nails to withdrawal immediately after they are driven into the softer woods. The increase is not permanent, but drops to about 1/2 after a month or so for the softer woods.

Nails with special coatings such as zinc are used where corrosion and staining are important in permanence and appearance. Any increased resistance to immediate withdrawal is usually reduced after wetting and drying cycles.

Chemically etched or sand-blasted nails have somewhat higher withdrawal resistance than other coated nails and may retain it under varying moisture conditions, but not under impact loading.

Nail shanks are shaped to increase surface area without an increase in nail weight.

Their withdrawal resistance, except some types of barbed nails, is generally greater than common nails in wood at a uniform moisture content. With changes in moisture content, some forms have greater withdrawal resistance than common wire nails, especially for nails driven into green wood that later seasons. In general, annular grooves increase withdrawal loads, and spiral grooves increase impact withdrawal.



Nails with various shank forms: A, annular thread for general use, especially in softwoods; B, spiral thread for hardwoods such as flooring and pallets; C, shallow thread for masonry nails.

A long, sharp point usually has a higher withdrawal resistance, particularly in softer woods, than the common nails, which usually have diamond points. Sharp points accentuate splitting. A blunt or flat point without taper reduces splitting and withdrawal resistance. Nails tapered to a blunt point split less than common nails, and have about the same withdrawal resistance in heavier wood but less in lighter wood.

Withdrawal resistance is generally greatest for nails driven perpendicular to the grain of the wood. With end-nailing withdrawal resistance is reduced in dense woods, and in softer woods may drop below 50%.

Slant driving is usually superior to straight.

The maximum strength of toenailed joints is obtained by using the largest nail that will not cause excessive splitting, allowing an end distance of about 1/3 the nail length, driving the nail at a slope of 30° with the attached member, and burying the full shank of the nail but avoiding wood mutilation.

The allowable withdrawal load per nail in toenailed joints for all conditions of seasoning is 2/3 of calculated withdrawal resistance.

Lead holes prevent or reduce splitting and increase withdrawal resistance.

Clinching increases withdrawal strength up to 170%. Clinch nails across the grain.

Small nails in plywood cause less splitting when near an edge. Withdrawal resistance is 70%-85% that of solid wood. For plywood less than 1/2" thick, less splitting offsets the lower withdrawal resistance. The withdrawal load per inch decreases with increase in the number of plys. Face grain direction has little influence.

*From the Forest Products Laboratory's "Wood Handbook," USDA Handbook No. 72

Lateral Resistance

The allowable load for a bright, common wire nail in lateral resistance when driven into the side grain (perpendicular to the wood fibers) of seasoned wood is:

$$p = KD^{3/2} \quad \text{Eq 115-2}$$

p, the allowable lateral load, lb/nail; K, a factor allowing for wood species and for safety factor; and D, the diameter of the nail, inches.

Ultimate lateral nail loads in softwoods are about 6 times, and in hardwoods about 11 times, the load p. The side member and the member holding the nail point have about the same density and nail penetration is not less than 10D for dense woods and 14D for light woods. When metal is held to wood, increase the allowable lateral nail load about 25%.

For end nailing, reduce p to about 60%.

Reduce the allowable load 25% for unseasoned wood that will remain wet or be loaded before seasoning takes place.

The erratic behavior of a nailed joint after moisture content changes prevents recommending an allowable lateral load.

Deformed-shank nails are about the same as common nails at design loads but are more apt to break under vibration or wrecking.

The National Design Specification, NFPA, specifies the following lateral loads for group II woods:

8d, 78#; 10d or 12d, 94#. Dr. George E. Stern of VPI has found adequate evidence that these values may be doubled when used in double shear, as in truss construction (VPI Wood Research Lab Bul 55, 1964).

The NDS gives no guide on nail spacing. The following are from FPL report 0100, 1965.

Nail spacing, minimum:

1-1/2" edge distance

1" across grain

2-1/2" parallel to grain

2-1/4" end distance in tension members

Spikes

Common wire spikes are manufactured the same as common wire nails. They have either a chisel point or a diamond point and are made in lengths of 3"-12". For corresponding lengths (3"-6"), they have larger diameters than the common wire nails, and beyond 60d they are usually designated by inches of length.

The allowable withdrawal and lateral resistance formulas and limitations given for common wire nails are applicable to spikes, except that, in calculating the withdrawal load for spikes, the depth of penetration should be reduced by 2/3 the length of the point.

CHAPTER 116 GLUING WOOD

Table 116-1. Wood glues.

PROPERTY	SYNTHETIC RESIN GLUES				PROTEIN GLUES		
	Resorcinol	Urea	Polyvinyl	Epoxy	Contact Adhesives	Casein	Animal
Needs Mixing	X	X		X		X	X
Crack-Filling			X	X	X	X	
Applied Hot							X
Applied Cold	X	X	X	X	X	X	
Colorless Glue Line		X	X		X	X	X
Dark Colored Glue Line	X						
Tends to Stain Certain Woods						X	
Pressed at 70°	X	X	X	X	X	X	X
Over 8-Hour Working Life		X	X				X
Low Moisture Resistance			X				X
Medium Moisture Resistance			X		X	X	
Good to High Moisture Resistance	X	X		X			
Low Temperature Resistance		X	X				
High Temperature Resistance	X			X	X	X	X
For Structural Gluing	X	X				X	
For Exterior Uses ¹	X			3			
For Interior Uses ²		X	X	3	4	5	X

¹Exterior uses include outdoor furniture, boats, and recreational equipment.

²Interior uses include furniture, cabinets, framing, and other shopwork that will be used in a moderately dry atmosphere.

³Excellent for bonding metal, plastics, and cloth to wood. No practical advantage on wood-to-wood gluing over resorcinol resin except it is a good joint filler.

⁴Covering counters and cabinets with leather, linoleum, and plastic laminates.

⁵Mold-resistant types are highly water resistant, though not waterproof.

Wood Selection

Heavy woods are usually more difficult to glue than lightweight woods. Hardwoods are more difficult to glue than softwoods. Heartwood is more difficult to glue than sapwood.

Use dry, smooth wood free of dirt, oil, and other coatings. Most purchased lumber has been planed and is sufficiently smooth.

Clean dirt, paint, and other coatings from wood with a scraper, wire brush, steel wool, or other abrasive. Do not use wood that has oil or grease at joint locations.

For structural members and those expensive to replace, use wood pressure-treated with oil-base preservatives if it will be exposed to wet conditions, soil, or termite attack.

Generally, preservative-treated wood must be planed prior to gluing for maximum holding power. Wood treated with oil-base preservatives tends to bleed; buy wood that has been steamed or otherwise cleaned until bleeding has stopped.

Moisture Content

Wood gains and loses moisture with humidity and temperature changes, causing wood to change dimensions and stressing joints.

Kiln-dried wood available at most lumber yards has about 15% moisture content. The moisture content of wood for interior home projects should be reduced to an average of 8% by storing it in an atmosphere similar to where it will be used. To assure uniform exposure to the air, place small blocks between the pieces. After several weeks the wood will usually be near an acceptable moisture level.

Exterior siding, trim, sheathing, and framing can usually be used as purchased. If the moisture content is above 15%, the wood should not be glued, but should be stored in a drier atmosphere for several days.

Glue Selection

No glue satisfies all requirements. Choose one for the requirements of one job. No glue is fool-proof. Well-made joints require woodworking skill and control of gluing conditions. Improper use of glues may result in costly repairs or replacements.

Consider expected length of service. In permanent structures, the few added dollars needed to buy a more resistant glue and Exterior plywood are well spent.

Recommended glue qualities for farm building construction:

- Water resistant for storage buildings and where the moisture content of the wood can be controlled (casein or resorcinol resin)
- Waterproof for livestock confinement buildings and where moisture problems are almost sure to occur: leaks in roof, outdoor furniture or equipment (resorcinol resin)
- Crack-filling—(gap-filling)
- Easy mixing
- Nail pressure for clamping
- Cold setting—cures without heat
- Moderate cost

Two types are recommended—casein and resorcinol resin.

Recommended glue qualities for most interior uses:

- Easy mixing or pre-mixed
- Moderate cost
- Medium pressure requirements (clamps or nails)
- Cold setting
- Does not stain the wood or leave a visible glue line

Several glues usually have these qualities. Urea resin is a good structural glue for drywood that will remain dry. Resorcinol resin and casein both leave visible glue-lines.

Construction adhesives

There is available an expanding array of adhesives useful in the construction—as opposed to prefabrication—industry. Products have been developed specifically for applying drywall panels, sub-floors, decorative paneling, etc. Elastomeric construction adhesives do not set rapidly (as do the contact cements, for example), retain some elasticity when cured, are water resistant (some may be waterproof), and will adhere to wood, metals, fiberglass, concrete, brick, and other materials.

Construction savings result from sub-floor panels being rigidly fastened to each other and to joists, from the ease of fastening materials to concrete floors and walls, from avoiding covering nail heads, and similar applications. Usually the adhesive is applied in a bead with a caulking gun; a single bead along a joist or stud, serpentine beads for panels, intermittent beads for low-load members.

Gluings

Follow manufacturer's directions.

Have the room temperature above 70°F. Lower temperatures slow curing.

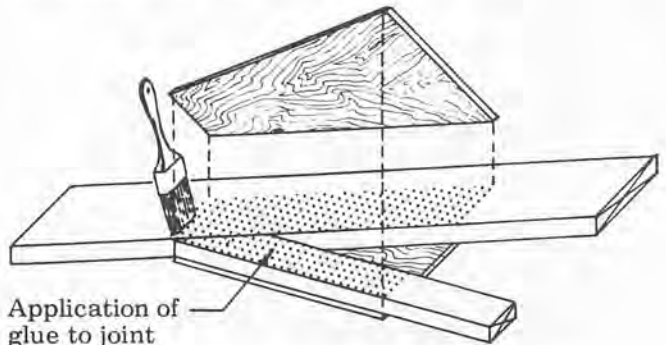
Follow mixing instructions, pot life (the length of time the glue stays usable after mixing), temperature during use, etc.

Foam, lumps, or too thick or too thin glue, lowers joint quality. The glue film should have no air bubbles or foreign particles and should completely cover the joint area.

Before gluing, test for good fit; pieces should make contact at all points. Crack filling glues can give a good bond despite small surface misfits. Glue a sample joint to test for staining.

The end grain of wood usually requires two coats. For farm construction, for heavy construction such as laminated timbers, or where the surfaces are rough and assembly periods may be long, spreading on both surfaces is desirable.

Apply enough glue. When pressure is applied, some glue should ooze out from around the joint. If it doesn't, you aren't using enough glue. Don't skimp; the cost of the glue is a minor item in the total cost of construction.



Application of glue to joint

Apply glue with a brush, stick or paint roller. Put pressure on the joint with clamps, nails, screws, or other fasteners before wiping off excess glue.

Assembly time

Assembly time is between spreading the glue and applying the pressure. "Open assembly" means the surfaces are open to air; "closed assembly" means the surfaces are in contact, but not clamped.

Permissible assembly time is reduced by: warm glue film temperatures, drier wood, the end of a batch of mixed glue, and only one surface coated with glue. Most glue containers have the assembly time and other precautions printed on the label.

Pressure

Pressure squeezes glue into a thin continuous film, forces air from the joint, brings glue and wood together, and holds them until the glue has set and cured.

Apply pressure uniformly over the entire joint. Keep joints under pressure at least until they have enough strength to resist separation—usually from 2 to 7 hours under favorable conditions. Leave pressure applied longer if possible.

Curing time

The time needed for curing depends on the glue type and the glue-line temperature.

The higher the glue-line temperature, the faster the glue will cure and the shorter the necessary clamping time. Room temperature means 70°F or above. The minimum temperatures for curing have not been well established, but below 70°F curing time is increased.

Durability

Durability depends on the type of glue, service conditions, gluing technique, and the design or construction of the joints.

Well-designed joints made with the proper glues will last indefinitely if the moisture content of the wood does not exceed approximately 15% and the temperature is within about -30°F to 110°F.

To increase the durability, use waterproof glue and preservative-treated wood, or use waterproof glue and apply preservatives to the wood after the joint is made.

Structural gluing

Wood must be clean and smooth, and be below 15% moisture. The surface of pressure-treated wood must be dry and free of bleeding preservative. Use unsanded (preferred) or sanded Exterior Plywood.

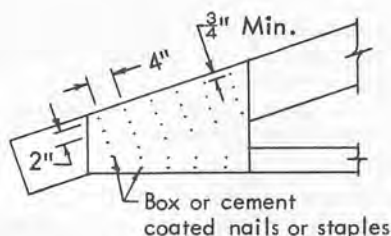
Use urea resin, casein, resorcinol resin, or a construction adhesive. Use resorcinol resin in treated wood. Use urea resin only for dry conditions. Casein can be used for moderately dry conditions; buy a glue that meets Federal Specification MMM-A-125 Type II. Apply glue at 40°F or above; 70°F recommended. Apply pressure as soon as possible. Maintain pressure for two days at 40°F, 4 hours at 70°F, or 2 hours at 80°F.

Use resorcinol resin for either wet or dry conditions. Buy a glue that meets Military Specification Mil-A-46051. Apply glue at 70°F or above. Assemble but wait 5 to 10 minutes before applying pressure. Maintain pressure for 10 to 16 hours.

Pressure is often applied with staples or box, galvanized, or cement coated nails. Finish driving staples with at least one hammer blow. At the end of the pressing time, the glued elements may be moved, but full load should not be applied for about one week.

Structural joints

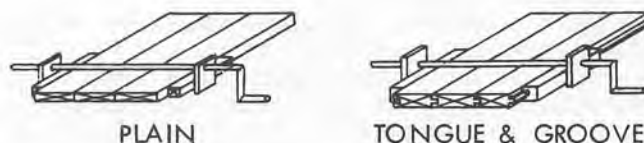
Joints connecting structural members are as critical as the members themselves. Use a nail for about each 8 square inches of the joint. The location and size of nails are usually given in a designed plan or in the engineer's recommendations.



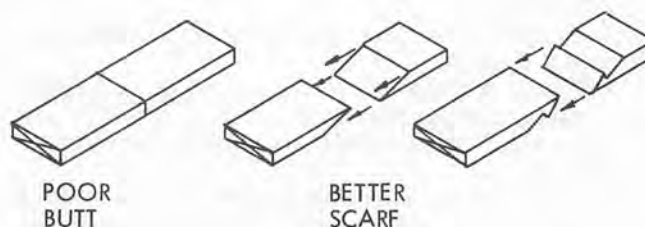
TYPICAL
TRUSS
JOINT

Non-structural joints

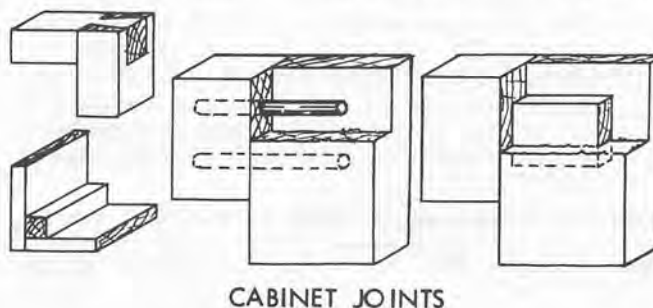
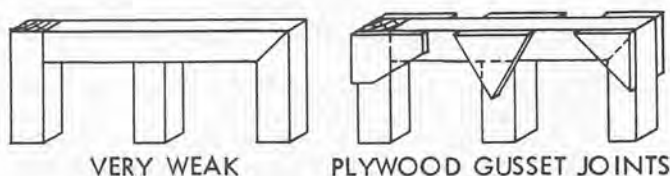
Edge-to-edge joints can be as strong as the wood itself. Tongue-and-groove lumber is easier to align, but the shapes may not fit snugly. A shallow tongue-and-groove is as effective as a deep one, and is less wasteful of wood.



End-to-end joints cannot be made to give the same strength as the wood itself. Use a shape that will give more glue surface area and, therefore, more strength.



End grain-to-side grain joints are difficult to glue. They have high joint stresses because of unequal dimension changes in the two pieces. End-to-side joints should be tightly fitted and held together by dowels, tenons, gussets, or other reinforcing devices.



CABINET JOINTS

CHAPTER 117 CONCRETE

Concrete is a mixture of Portland cement, water, air and aggregates. Portland cement is sold in bulk, or in bags of one cubic foot (94 pounds). The aggregates provide volume at low cost, composing 66%-78% of the concrete.

The cement and water form a paste that hardens and glues the aggregates together. The quality of concrete is directly related to the binding qualities of this cement paste.

Concrete can be made to take almost any shape. It is used widely in residential work due to its fairly low cost and the ease of handling small batches by the amateur. Most structural uses involve reinforced concrete, which depends on concrete's strength in compression and steel's strength in tension.

Concrete can be finished in either a smooth or rough texture. It can be colored with pigments and can be painted.

Portland Cement

Portland cement got its name from the Isle of Portland, near England, where it was first developed. This improvement over an ancient building material is made by burning limestone and clay, adding gypsum, and grinding the result to a fine consistent powder.

A number of variations have been developed for special purposes.

- Type I, normal Portland cement, is a general purpose type, the most common, and the type usually furnished unless an alternative is specified.
- Type II is modified to release less heat during curing, and is therefore suitable in mass concrete—heavy retaining walls, or deadmen for suspension bridges. It is moderately high in resistance to sulphates. Type II is replacing Type I as the basic type in some areas.
- Type III is high-early-strength; it is very finely ground and sets very rapidly. It is useful for slip-form construction and for cold weather jobs.
- Type IV is the lowest heat variety, and while suitable for large masses, develops strength relatively slowly. Its primary use is for mass-concrete dams and other large-volume structures.
- Type V is especially sulphate-resistant and cures more slowly than Type I.
- Types I, II, and III are available as Types IA, IIA, and IIIA. These are air-entrained Portland cements formulated with a compound that releases many tiny bubbles of air during curing. The resulting concrete is highly resistant to frost action, and has some increased resistance to salts. Its use is recommended for all outdoor paving and for concrete exposed to animal wastes, even though slightly weaker than Type I.

Table 117-1. Recommended air content for air-entrained concrete:

Max. Aggregate Size	Amount Of Air, %
1½", 2", or 2½"	4 to 6
¾", or 1"	5 to 7
3/8" or ½"	6½ to 8½

Table 117-1 suggests the recommended amounts of air entraining related to aggregate size.

Other additives include pigments for coloring, gypsum to retard setting time, calcium to reduce setting time, and bentonite to improve workability.

Water

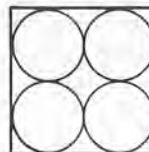
Cement in concrete cures by the chemical combination of water and cement—not by drying like sheets in the sun. Use water for concrete that is essentially good enough to drink, and without harmful chemicals, trash or organic matter.

The strength of concrete is greatly dependent on the water-cement ratio. Enough water is needed for full curing, but excess water leaves voids when it evaporates. If a mix is too stiff to handle well, do not add water; reject the batch or add cement and water—reduce the amount of aggregates in subsequent batches.

Aggregates

Sand and gravel, the usual aggregates, are glued together by the cured cement paste. They must be free, or very low, in silt and organic matter, and they must be hard and strong.

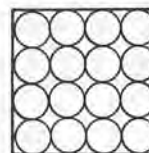
Particles up to 1/4" are classed as sand, above 1/4" are gravel. Well graded aggregates occupy most of the volume of the concrete, minimizing the amount of cement paste, which is the expensive ingredient. Using spheres for illustration, large balls have less surface area than small ones, requiring less cement. But, small balls fit in between the large ones to help fill up the voids.



2" cube holds 8-1" balls;

$$\text{volume} = 8(4\pi r^3/3) = 8(0.5236) \\ = 4.189 \text{ in}^3$$

$$\text{surface} = 8(4\pi r^2) = 8(3.14) \\ = 25.13 \text{ in}^2$$



2" cube holds 64-1/2" balls;

$$\text{volume} = 64(0.06545) = 4.189 \text{ in}^3 \\ \text{surface} = 64(0.785) = 50.26 \text{ in}^2$$

Each size fills just one-half the volume, but the smaller ones have twice the surface area. Therefore, an economical mix is one that uses the largest practical size of aggregate, plus smaller aggregates to fill as many voids as possible.

The moisture in the aggregate is part of the water needed to react with the cement.

Mixing

Trial mixes are recommended in Table 117-2.

Mix concrete at least one minute after all ingredients have been added, for batches up to one yard. Add 1/4 minute for each additional 1/2 yard or fraction.

Table 117-2. Concrete Mixes

		¹ Gallons of water for each sack of cement, using:			² Suggested mixture for 1-sack trial batches			READY-MIX Sacks Cement Per Yard ⁶
	Max. size aggregate	Damp ³ Sand	Wet ⁴ (average) Sand	Very ⁵ Wet Sand	Cement, sacks (cu ft)	Aggregates		
						Fine cu ft	Coarse cu ft	
5-Gallon Mix; use for concrete subjected to severe wear, weather, or weak acid and alkali solutions.	¾"	4½	4	3½	1	2	2¼	7¾
6-Gallon Mix; use for floors (home, barn), driveways, walks, septic tanks, storage tanks, structural concrete.	1"	5½	5	4½	1	2¼	3	6¼
	1½"	5½	5	4½	1	2½	3½	6
7-Gallon Mix; use for foundation walls, footings, mass concrete, etc.	1½"	6¼	5½	4¾	1	3	4	5

¹Increasing the proportion of water to cement reduces the strength and durability of concrete. Adjust the proportions of trial batches without changing the water-cement ratio. Reduce gravel to improve smoothness; reduce both sand and gravel to reduce stiffness.

²Proportions will vary slightly depending on gradation of aggregates.

³Damp sand will fall apart after being squeezed in the palm of the hand.

⁴Wet sand will ball in the hand when squeezed, but leaves no moisture on the palm.

⁵Very wet sand has been recently rained on or pumped.

⁶Medium consistence (3" slump). Order air-entrained concrete for outdoor use.

Yield

As shown in the discussion of aggregates, sand fits in between gravel, and pastes in the remaining voids and around each particle. In a 1:2-1/4:3 (cement:sand:gravel) mix, the volume of concrete is not 1 + 2-1/4 + 3.

The volume yielded is the sum of the absolute volumes of the ingredients.

Mass volume = Unit weight

specific gravity x unit wt water

Example, for cement:

$$\text{Mass volume} = \frac{94}{3.15 \times 62.4} = 0.478 \text{ cu ft/cu ft}$$

Table 117-3. Mass volumes of concrete materials.

Material	Specific gravity (ratio)	Unit Weight (lb/cu ft)	Mass Volume (cu ft/cu ft)
Water	1	62.41	12
Cement	3.15	94	0.478
Sand	2.65	110	0.665
Gravel	2.65	100	0.605

17.48 gal/cu ft ²0.134 ft³/gal

Absolute volume = Bulk volume in mix x mass volume.

In a mixture, the absolute volume is the material's bulk volume times its mass volume; for sand to be 2-1/4 ft³/batch

$$\text{absolute volume} = 2\text{-}1/4 \times 0.665$$

For the 1:2-1/4:3 mix with 6 gal water/sack:

$$\text{Cement} = 1 \text{ ft}^3 \times 0.478 = 0.478 \text{ ft}^3$$

$$\text{Sand} = 2\text{-}1/4 \times 0.665 = 1.496$$

$$\text{Gravel} = 3 \times 0.605 = 1.815$$

$$\text{Water} = 6 \text{ gal} \times 0.134 = 0.804$$

$$\text{Volume yield} = 4.593 \text{ ft}^3/\text{batch}$$

The ingredients needed:

$$\text{no. sacks} = \text{concrete volume needed/yield}$$

$$\text{sand} = \text{no. sacks} \times 2\text{-}1/4$$

$$\text{gravel} = \text{no. sacks} \times 3$$

For one cubic yard (27 ft³)

$$\text{no. sacks} = 27/4.593 = 5.9 \text{ sacks}$$

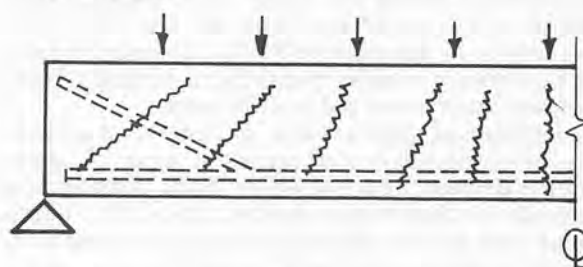
$$\text{sand} = 5.9 \times 2\text{-}1/4 = 13.3 \text{ ft}^3$$

$$\text{gravel} = 5.9 \times 3 = 17.7 \text{ ft}^3$$

Because concrete is relatively strong in compression, and both relatively weak and unpredictable in tension, concrete is reinforced with steel bars where tension is to occur.

The following are important variables.

- Bending strength, f_c , is the maximum bending compressive stress in concrete, psi.
- Shear, v_c , is a measure of diagonal tension at points of maximum vertical shear, psi. The tension is visible as fine cracks near the end of a beam.



- Elasticity, E_c and E_s , measures the change in length of a material with applied load, and is used to convert load on a member to deflection, psi.
- Tensile strength, f_s , is the maximum tensile strength of steel, psi.
- Perimeter, ϕ , is the effective circumference of a steel bar, in. Because the bars are deformed to increase bond, they are not uniform in cross section or perimeter, in.
- Length for full bond, in., is the least length that will develop bond stress equal to the bar's tensile strength:
- Moment of inertia, I , is a property of the size and shape of the beam's cross section, in.⁴

CHAPTER 119—PAINT

Introduction

All opaque paints are composed of pigment and vehicle. The pigments contribute color, opacity, weather resistance, and other properties. The vehicle consists of a nonvolatile portion, or binder, and a volatile portion, or thinner. The binder contributes adhesion to the surface, flexibility, and also controls the permeability of the film. The thinner, or solvent, regulates the consistency, application properties, and leveling. Other ingredients to control fungus, settling, and other properties may be present. A paint formulation may contain as many as 15 different ingredients.

Water Paints

All water paints use water for at least part of the thinner. Water paints may be latexes, usually acrylic, polyvinyl acetate (vinyl or PVA), or styrene-butadiene ("rubber-base"); they may be emulsion paints, usually based on linseed oil or alkyd resins; or they may be water solutions, such as calcimine, casein paints, or dry-powder Portland cement paints. Some new water-soluble resins have recently been developed, but are not yet widely used.

Water-thinned paints have a number of advantages, including ease of application, ease of clean-up, quick drying, and low odor. Their outstanding advantage is that they can be applied to damp surfaces, and can be applied during humid weather.

Latex paints are the most commonly used water paints. Latex paints are generally highly alkali-resistant, which allows their use over freshly applied concrete or plaster. They are usually porous, allowing any moisture in the wood or masonry to escape without blistering the paint film. On the other hand, they are generally nonpenetrating, which makes their use on old, chalky paint surfaces very risky. Also, if the moisture coming through the film carries any color, as it may with red cedar or redwood, the paint is likely to be stained. Porous paints should not be used over unprimed iron, since moisture going through the film will rust the iron, and the iron oxide formed will stain the film.

Solvent Paints

Solvent paints contain pigments, and a binder of oil, varnish, or a resin dissolved in a volatile solvent. The solvents are usually flammable, although many have relatively high flash points. Solvent paints dry by solvent evaporation, oxidation, polymerization, or some combination of these reactions. Conventional exterior house and barn paints have a drying oil—usually linseed—as the binder. Harder coatings, such as trim and machinery enamels, use either alkyd resins or oleoresinous varnishes, such as tung-phenolic, for the binder. Exterior masonry paints are likely to be made with more alkali resistant resins, such as chlorinated or synthetic rubber types. Numerous other resins, such as epoxies, urethanes, and polyesters are used for specialized purposes.

The pigments in a solvent paint are selected for the color and end use of the product. Most exterior house paints contain titanium dioxide, white lead, zinc oxide, and extender pigment. The amount of chalking can be regulated by the grade of titanium dioxide used. White paints usually chalk in order to keep the surface white and clean. Tinted paints, or those designed for tinting on the job, are more chalk-resistant. Chalk-resistant paints are recommended for use on wood over a brick wall where the chalk running down on the brick would be objectionable.

Pure white lead in linseed oil is a very durable paint and used to be the standard exterior paint. It has lost popularity because it is expensive, does not hide well, and darkens and collects dirt on exposure. Use lead-free paints where darkening from hydrogen sulfide would be objectionable and where livestock or children might eat any loose flakes.

Paints containing zinc oxide should not be used as primers on the first coat for wood surfaces because zinc paints are usually prone to blistering.

Barn paints are usually pigmented with iron oxide, which is extremely durable, but limited in its color range. The most durable barn paints contain about 55 percent pigment of which at least 30 percent should be iron oxide.

The pigmentation of enamels is determined by the color desired. White enamel is primarily titanium dioxide.

Interior paints are almost always lead-free since the durability of white lead is not needed. White lead is expensive, and there is the hazard that children or animals may eat flakes which become detached.

Indoor Painting

There are three basic steps to follow for painting. The first is to select the right paints for the various surfaces to be painted. The surfaces must then be adequately prepared, and finally, the selected paint must be properly applied.

Selecting paints

Choose paints that will provide cleanliness, durability, and beauty. Also choose paints that will fit in with the room, and can be used over the material and texture of the surface. Consider the type of finish that is desired. Glossy finishes clean easily and look shiny. Flat finishes absorb light, reduce glare, and show dirt and dirt marks quite readily. Semi-gloss finishes have properties of both glossy and flat finishes.

Color

The best color for a room or project is often hard to determine. Color can make things seem larger or smaller than they really are, can be used to highlight areas of importance, and will affect the psychological reactions of people and animals. Interior decorators and some paint dealers can help in selecting appropriate colors.

Table 119-1. The light reflectance of various colors.

White.....	80%	Salmon.....	53%
Ivory (Light).....	71%	Pale Apple Green.....	51%
Apricot-beige.....	66%	Medium Gray.....	43%
Lemon Yellow.....	65%	Light Gray.....	41%
Ivory.....	59%	Pale Blue.....	41%
Light Buff.....	56%	Deep Rose.....	12%
Peach.....	53%	Dark Green.....	9%

Livestock buildings

The walls and partitions in farm service buildings sometimes need a very resistant paint. For surfaces that must withstand almost constant rubbing of animals, and for surfaces that must frequently be cleaned of manure and dirt, apply epoxy paint. Epoxy paints come in two containers, must be mixed carefully, are washable and quite durable, and are usually more expensive than ordinary paint.

For surfaces that will not be exposed to excessive wear or washing, use a good moisture-resistant paint.

Surfaces

Walls and ceilings in bathrooms and kitchens, and trim around doors and windows should be painted with enamel or semi-gloss paints as these areas need to be cleaned often.

Plaster that has not aged at least three months, should first be primed with a "lime- or alkali-resistant" paint.

For acoustical tile, use flat paints thinned according to the manufacturer's directions.

Woodwork, paneling, and wood floors to be finished with a natural finish may first need to be stained and filled with wood filler. Talk with a cabinet maker and your paint dealer for the procedures to use for staining and filling.

Some common finishes applied to concrete floors are epoxy and polyurethane paints, linseed oil paints, and butadiene styrene paints. Your paint dealer can help you select the paint best suited to your surface.

Table 119-2. Paint or finish to use indoors.

	Aluminum Paint	Casein	Cement Base Paint	Emulsion Paint (Incl. Latex)	Enamel	Flat Paint	Floor Paint Or Enamel	Floor Varnish	Interior Varnish	Metal Primer	Rubber Base Paint (Not Latex)	Sealer Or Undercoater	Semi-Gloss Paint	Shellac	Stain	Wax (Emulsion)	Wax (Liquid Or Paste)	Wood Sealer
Floors																		
Asphalt Tile							X									X	X	
Concrete							X	X								X	X	
Linoleum							X									X	X	
Vinyl and Rubber							X	X								X	X	
Wood																X	X	X
Masonry -- Old	X	X	X	X	X	X				X	X		X					
New			X	X	X	X				X	X		X					
Metal																		
Heating Ducts	X				X	X												
Radiators	X				X	X			X	X			X					
Steel Cabinets					X	X			X	X			X					
Stairs																		
Treads							X	X										
Risers									X				X	X	X			X
Walls and Ceiling																		
Kitchen and Bathroom																		
Plaster		X		X	X					X	X		X					
Wall Board		X		X	X					X	X		X					
Wood Paneling				X	X					X	X		X					
Wood Trim				X	X	X		X		X	X		X	X	X		X	X
Windows																		
Aluminum	X				X	X			X	X			X					
Steel	X				X	X			X	X			X					
Wood Sills					X			X			X				X			

X. Black dot indicates that a primer or sealer may be necessary before the finishing coat (unless surface has been previously finished).

Preparation

New Surfaces

New surfaces, except concrete and plaster, can be painted after they are cleaned of all dirt and grease. Holes or other imperfections made during construction should be repaired before painting begins.

Concrete floors should not be painted until the concrete has aged at least 3 months. Slick concrete floors should be roughened before being painted. Treat slick floors with 1 gallon of muriatic acid mixed in 2 gallons of water. Brush the acid into the floor until it fizzes in every area. Rinse the acid off with clear water, examine the floor, and re-treat the spots that were not roughened. Coarse floors with an even texture can be painted without an acid treatment.

Paint will not fill the pores of brick, block, or stucco. These surfaces must be plastered if a smooth surface is desired.

Old Surfaces

Remove all dirt, grease, and wax. A dry rag or mop will usually remove enough dirt. A kitchen usually requires washing with a mild detergent to remove dirt and grease. Wax can be removed with turpentine, mineral spirits, or a wax remover.

Before painting wood that contains an oil stain, wash the surface with mineral spirits, sand, and apply a good sealer or undercoat.

Remove all door hardware, switch plates, and other fixtures that would interfere with painting.

Fill all cracks and holes. Small hairline cracks in plaster can be filled with spackling compound. Larger cracks and holes should be made into an inverted "V" shape and filled with plaster or spackling compound. The "V" shape provides some anchorage for the filler. All repaired cracks and holes should be sanded smooth after the filler is completely dry.

Holes, cracks, and dents in wood can be filled with many available types and colors of wood fillers. Be careful not to smear the filler on adjacent wood. Smooth the repair after it has dried. Sand and prime all bare areas of wood.

If a surface is glossy or very smooth, roughen it slightly with sandpaper or other abrasive. In some cases, washing it with a strong detergent, followed by rinsing, will be sufficient.

Holes and cracks in masonry and concrete can be filled with cement-sand mortar or prepared "crack filler," special caulking cement or latex concrete patching kits.

Holes in metal can be filled with silicone rubber, plastic, steel or aluminum, and special epoxy metal glues.

Apply a moisture-resistant prime coat to all repaired cracks, joints, and patches.

Application procedures

Apply a prime coat to new plaster, repaired surfaces, and unpainted surfaces.

Apply paint when the room and paint temperature is about 70°F. Provide cross ventilation to shorten drying time, and remove odors and fumes. Fumes are especially harmful to pet birds.

When painting a ceiling, work across the width rather than the length of the room. Don't try to paint a strip more than two feet wide. This will enable you to begin the second strip before the first has dried. It is best to use flat paint, somewhat thinned, for painting acoustical tile.

Paint the woodwork only after the walls are completely dry.

Wipe up splatters or drips while they are fresh. Within 24 hours after painting, remove all paint flecks from hardwood floors with steel wool and hardwood floor "wax and cleaner."

Place paint-filled rags in a fireproof container or burn immediately when discarded.

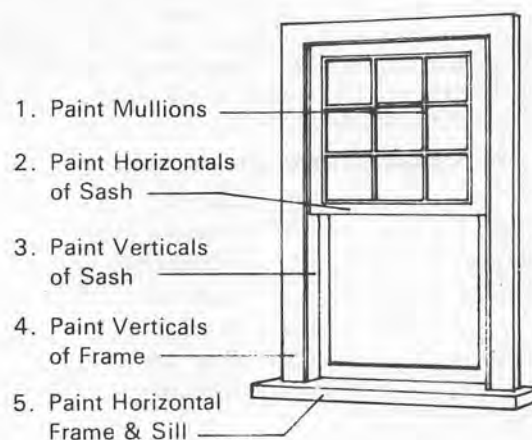
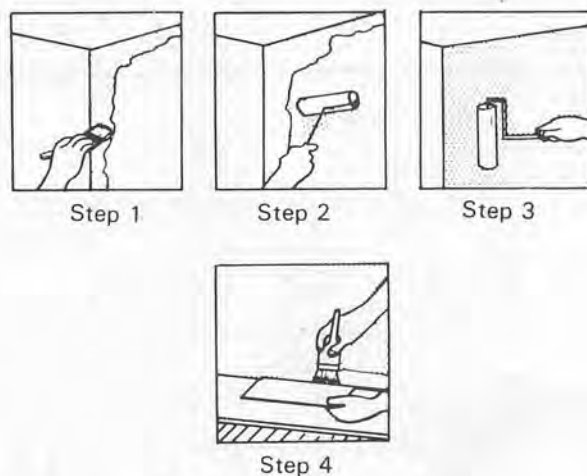


Fig 119-1. Painting windows.



At Floor or Baseboard

Fig 119-2. Using a roller.

Outdoor Painting

The three basic steps of painting also apply to exterior painting. See *INDOOR PAINTING*.

Selecting paints

Choose paints that have the desired color, can be applied successfully over the material needing paint, and can withstand the weathering or special conditions in your locality. It is good economy to buy a quality paint. Quality paint will lengthen the time between repainting, and thus reduce labor costs.

Tinted paints have a slightly longer service life than white paint, and dark-colored paints last even longer.

Color

Choose the paint color that will blend with the surroundings of the house, and also will satisfy your own preferences. White or light-colored buildings and objects attract attention and tend to become the center of interest. Darker colors such as reds, browns, greens, and grays are modest and tend to blend the building or object with the background.

Surface material

Wood and most metals can be painted with either solvent or water base paint. These materials require a primer coat to seal the surface against moisture.

The ingredients required in metal primers are listed in the section on "Painting Metal". The primer for trim and dark-colored paints is sometimes of a special formulation. Use a tinted primer under dark-colored paint.

Some lumber used for siding is primed at the factory and does not need a prime coat. Follow the lumber manufacturer's recommendation on the paint to use for a top coat. In most cases, they recommend a standard house paint.

Chalk-resistant paints should be used where chalk run-down would discolor masonry or metal. Where run-down would not be objectionable, the self-cleaning chalking paints could be used.

Porches, steps, and screens should be painted with abrasion-resistant paints. There are several types of paint that are specially formulated for this kind of surface.

Special solvent-thinned trim paints are available for wood trim, screen frames, shutters and other small areas of a house.

Rough-sawn lumber, dense smooth woods, and knotty or flat grain boards or plywood of oak, pine, spruce and fir can sometimes be more economically stained with a heavy pigmented oil stain rather than painted. See *Forest Products Laboratory Stain*.

Old painted surfaces often present special problems. As an example, chalky surfaces will not give a sound base for water-thinned emulsion paints, but may be adequate for water-thinned linseed oil paints. Be sure to follow the instructions of the manufacturer and paint dealer. They will likely recommend a solvent-thinned primer for emulsion paint.

Another example is old painted surfaces that have blistered, peeled, or cracked. There are special blister-resistant paints available that can help keep this from happening again. But, the cause of the blistering and peeling must first be found and repaired. See *Moisture Problems*. Blister-resistant paints may be either solvent or water-thinned, and must be applied as directed.

Masonry and asbestos-cement surfaces should be painted with alkali-resistant paint. Some latex paints, Portland cement paint, and solvent-thinned stucco and masonry paints are all satisfactory for masonry. Be sure that you buy alkali-resistant paint.

Table 119-3. Paint or finish to use outdoors.

	Aluminum Paint	Cement Base Paint	Exterior Clear Finish	House Paint	Metal Roof Paint	Porch-And-Deck Paint	Primer Or Undercoater	Rubber Base Paint	Spar Varnish	Transparent Sealer	Trim-And-Trellis Paint	Wood Stain
Wood												
Natural Finish		X										X
Porch Floor					X							
Shingle Roof												X
Shutters				X.		X				X.		
Siding	X	X		X.		X						X
Windows	X			X.		X				X.		
Metal												
Copper						X	X					
Galvanized	X.			X.		X	X			X.		
Iron	X.			X.						X.		
Roof				X.								
Siding	X.			X.	X.					X.		
Windows -- Aluminum	X			X.						X.		
Windows -- Steel	X.			X.						X.		
Masonry												
Asbestos Cement				X.		X	X					
Brick	X	X		X.		X	X			X		
Concrete Block	X	X		X.		X	X			X		
Concrete Porch Floor					X		X					
Stucco	X	X		X.		X	X			X		

X. Black dot indicates that a primer or sealer may be necessary before the finishing coat (unless surface has been previously finished).

Conditions

A local paint dealer can tell you what local conditions should be protected against—fumes, high humidity, or some special weathering condition. Choose a paint formulated to resist the special conditions of your locality.

Preparing to paint

All surfaces must be cleaned of dirt, oil, scale, and other impurities. Surfaces should be cleaned and dusted just prior to painting.

All materials and equipment needed for painting should be collected and ready for use. These would include the paint, extra cans for mixing, paddles for stirring, strainers to take out lumps that may be in the paint, and the material to clean painting equipment.

Also needed is the means of applying paint—brushes, spray equipment, or rollers. A 4- to 5-inch brush works well for large areas; a 1½- to 2-inch brush for trim; and a sash brush or narrow brush for narrow strips as those in windows.

Nylon bristle brushes are better than natural bristle brushes for latex paints. A natural bristle brush should be conditioned by soaking it in linseed oil for a day or two before painting oil paints. Soaking is not needed for nylon bristles or water-thinned paints.

Follow the manufacturer's recommendations carefully when using rollers or spray equipment.

Other equipment that may be needed: rags for cleaning; drop cloths for protecting porches, floors, roofs, shrubbery, and plants; ladders or scaffolding.

Preparing wood surfaces

New Construction

Wood siding should not contain knots or sappy streaks. If it does, the knots and streaks should be cleaned with turpentine and sealed with a good knot-sealer.

Wood siding and trim should be protected from the weather until it is installed. Structural defects must be repaired. Nail heads should be set below the surface of the wood, primed, and then puttied. This is especially true for rusting type nails. Always use non-rusting nails if possible.

Smooth any rough spots with sandpaper or other abrasive. Always dust just prior to painting.

Repainting

Wash dirty surfaces with a mild synthetic detergent and rinse thoroughly. Remove all rust marks and set all nail heads, prime, and apply putty. Any loose siding should be renailed with non-rusting nails.

Remove any rough, loose, flaking, or blistering paint and repair the cause of the problem. See *Moisture Problems*. If deep cracking, blistering, or alligatoring is extensive, remove ALL old paint, repair defects, and prepare to paint as new construction. Defective paint can be removed with a paint remover, scraper, sandpaper, wire brush, or other good abrasive. Do not use a blow torch unless you are an experienced user.

Preparing metal surfaces

Remove all rust, oil, and grease, and smooth roughened surfaces. A wire brush, steel wool, or sandpaper will usually remove rust and rough areas. Remove oil and grease with solvents such as mineral spirits, and then rinse thoroughly. A primer must be applied immediately after cleaning. See *Painting Metal*.

Preparing masonry surfaces

Patch or caulk all cracks and indentations, and apply an alkali-resistant prime coat. Install drain tile, drains, or water barriers where underground water pressure may cause water to come through a wall or floor. Paint will not hold back ground water under pressure.

New masonry and concrete basement walls should have their underground exterior surface painted with asphalt waterproofing before dirt is backfilled.

Remove all dirt, loose particles, oil, efflorescence, and old paint that is loose, peeling, or heavily chalked. Efflorescence is a white salt-like material adhering to concrete or mortar and is caused by moisture which dissolves salts within masonry and carries it to the surface. Dirt, efflorescence, and loose particles can usually be removed by washing the surface with a cleaner or detergent and water.

Poured or precast concrete may have a "release agent" on the surface which must be removed with solvent or by several months of weathering. Loose, peeling, or heavily chalked paint can be removed by sandblasting. If old paint is just moderately chalked but is otherwise "tight" and non-flaking, it should be coated with a conditioner if the surface is to be repainted with a water-thinned coating. Follow the paint manufacturer's recommendations.

Masonry floors, decks, porches, and patios may require a special treatment to provide an adequate base over which to apply paint. Manufacturers of paints for this kind of surface usually give instructions on how to prepare these surfaces. See *Preparing to Paint New Surfaces*.

Iron, copper, or other metallic objects imbedded in masonry surfaces to be painted with water-thinned paints must be primed with a good anti-corrosive primer.

After all impurities are removed or primed, wash or hose the surface. Do not wash or hose the surface if efflorescence was present. Allow the surface to dry thoroughly if solvent-thinned paints will be applied. The surface need not be completely dry for water-thinned paints.

Application procedures

Apply paint in reasonably clean, dry weather with the air temperature above 40°F., preferably 50°F. or higher. The paint temperature should be about 70°F. for easy stirring and spreading. Apply solvent paints only when the surface is dry. Several days' drying time may be needed after a rain. Water-thinned paints may be applied to a surface that is damp but free of liquid water. Do not paint during windy or dusty weather, or when insects may get caught in the paint coat.

In hot weather, paint surfaces after they have been exposed to the sun and are in the shade. If painting must be done in the hot sun, avoid over-thick application of the paint. Brush the paint out well.

Most paint manufacturers recommend applying a prime coat of paint to seal the surface against moisture. Use a primer recommended by the paint manufacturer. Apply a prime coat to all new surfaces, to all repaired surfaces, to surfaces that have little old paint left, and to old surfaces that are very chalky. Prime after all the repairing and cleaning is completed, but before filling with putty.

The Forest Products Laboratory recommends applying a water-repellent preservative before priming new wood that has not been so treated. The preservative contains penta and should be allowed to dry for two warm, sunny days before applying the primer. Ask your paint dealer about the recommendation of his paint manufacturer.

Use a zinc-free oil-base primer for new wood and spot priming when the top coats will be a solvent-thinned paint. Most manufacturers recommend using a solvent-thinned primer when the top coat will be an exterior emulsion or latex paint.

Allow a solvent-thinned prime coat to dry about three days in fair weather and four days in humid weather, unless the instructions on the label indicate a shorter time is satisfactory.

After a surface is primed, apply any caulking that is needed. Examples: around window and door trim; where different materials come together—joints between flashing and bricks; joints in wood siding; and at corners of buildings.

Apply the finish coats of paint immediately after the primer has dried sufficiently and all caulking has been done. If you cannot apply the finish coats within a month, wash the surface thoroughly before applying the top coats.

Allow about 48 hours' drying time between solvent-thinned finish coats. Two coats of latex paints may be applied in one day.

Three coats of paint are recommended for new work—one primer and two finish coats. However, properly designed and properly applied two-coat systems will usually give good durability. Three top coats are often recommended for south exposures, but other exposures should not have more than two top coats. When repainting, if a surface is in good condition, one additional finish coat is often sufficient. If the old paint is very thin, two coats should be applied.

Place paint-filled rags in a fireproof container or burn immediately when discarded.

Painting With A Brush

Always paint along the grain of wood, keeping an even pressure on the brush. Use long sweeping arm strokes. Dip a brush into the paint to about one-third the length of the bristles. Tap off the excess paint on the inside of the can. Do not scrape the brush across the rim. Apply the paint from the end of the brush, not from the sides.

A house or building should have the sash, trim, and doors painted first. On siding, begin at a corner or under the eave, and paint the under edge first. Paint from top to bottom, then begin again at the top. Complete one sidewall before starting another.

Always apply paint to an unpainted area and work the paint toward the wet edge of previously painted portions. Apply a finish coat generously, then brush out. When a section has been covered, go over the entire area with light, quick strokes to smooth all brush marks and laps, and to recoat any thin spots.

Cleaning Brushes

Soak brushes in the solvent recommended by the paint manufacturer. Loosen the paint within the bristles with the fingers. Rinse thoroughly with solvent. It is often recommended to then wash the bristles with mild soap suds and rinse thoroughly with water. Twirl the brush between the hands to remove excess water, and comb the bristles carefully. Wrap the brush in heavy paper, add several moth-repelling flakes, and store it laying flat.

Painting Metal

Paint only when the surface is clean and dry. Apply a primer to new metal and to metal that has had old paint removed. Good primers will have zinc-dust, red lead, zinc yellow, blue lead, oxide of iron, or zinc-dust oxide as one of its ingredients. Zinc-dust paints must be stirred frequently.

After the primer has dried sufficiently, apply one or two coats of finish paint. Most ordinary house or trim paints can be applied as finish coats over any of the recommended prime coats. For the finish coats on gutters, downspouts, flashings, nail heads, hardware or grilles, use conventional house paints or exterior enamel. Steel or aluminum windows can best be coated with house paint, aluminum paint, or exterior enamel. Window screens should have a special screen enamel applied.

Painting Galvanized Metal

It is not necessary to weather or treat galvanized steel before painting. Do clean the surfaces as outlined in *Preparing Metal Surfaces*.

After cleaning, prime areas which have no galvanizing, due to handling or age. Then apply finish coat or coats.

Zinc-dust paints in an oil, alkyd, or phenolic base adhere best to galvanized surfaces under most conditions. Cement paints in an oil base work nearly as well, and are recommended where color is desired. Latex paints made for galvanized steel

are being used but have not been tested as extensively as other metal paints. These latex paints seem to be especially suitable for single-coat coverage.

A recommended paints will usually not peel if applied properly. One coat of paint will do the job, but two coats are usually better.

Natural or stained finishes

There are two types of natural finishes—surface coating finishes and penetration finishes. Surface coating is not very durable and must be refinished every year or two to prevent discoloration in the woods. Some penetrating finishes are very durable.

Spar varnish or synthetics are applied in three coats. They are transparent and if the wood is fully exposed, it must be refinished every year and sometimes more often. These finishes tend to build up on the surface and crack. Removal of the finish to the bare wood is necessary when this occurs.

Penetrating finishes include wood sealers or drying oils such as boiled linseed or raw linseed to

which paint driers have been added. The finishes may contain a coloring pigment. These finishes soak into the wood and are applied in two coats on new wood and one coat when refinishing. It is best to add fungicides to prevent mildew.

Shingle stains are opaque and more nearly represent a paint. They are particularly suited to rough surfaces and will normally give four to five years' service. They are not suited for use on doors, windows, and similar trim that require a preservative coat.

Forest Products Laboratory Stain

Ingredients and methods of application for a stained finish on wood is explained in detail in the Forest Products Laboratory publication, FPL-046. You can obtain a copy from the Forest Products Laboratory, USDA, Madison, Wisconsin 53705.

The stain, based on durable red and brown iron oxide pigments, adequately applied to rough surfaces will last up to 10 years. When refinishing is necessary, the rough surface-stain system is easily renewed without extensive surface preparation.

120 LOADS

CHAPTER 121 DEAD, SNOW, AND WIND LOADS

Introduction

Four general types of loads act on farm buildings—dead, live, snow, and wind loads. Dead loads are the weights of structural materials. These loads remain constant in intensity and in point of application during the life of a building. Snow and wind loads depend on climate. Live loads include stored products such as silage, grain, and hay. Live loads vary both in intensity and in point of application. For information on live loads see chapters 122, 123, and 124.

The intensity of loading used in farm building design may differ from that specified for public and commercial buildings in building codes. It will usually be lower in farm building design, because the consequences of failure are much less severe, for example, in a machine shed than in a highschool classroom. Particularly in temporary farm buildings, but even in buildings that are expected to last for many years, the owner is usually willing to accept a somewhat greater risk of failure for a lower initial cost.

The loads farm buildings are subjected to are variable and complex. Snow and wind loads, for instance, vary with the location and the height of the building, as well as with the building's shape and roof slope. Finally, recommended loads vary with the expected life and use of the structure and an estimate of the risk to human life.

The American National Standards Institute has developed recommendations for dead, live, snow, and wind loads suitable for acceptance into building codes. These are published as ANSI A58.1-1972, "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures." Parts of the following material were extracted from this publication. An abstract and commentary are in the "Professional Design Manual," MWPS-17. This load standard is currently being considered for acceptance by the American Society of Agricultural Engineers.

Building Classes and Design Intervals

The mean recurrence interval is the number of years during which, on the average, an event is expected to occur only once, and is the reciprocal of the statistical probability of the event occurring during any one year.

The large amount of weather data available have permitted analysis of the snow packs and wind velocities likely to be exceeded only once during the indicated mean recurrence intervals. The maximum snow pack or wind velocity and when it will occur are not predicted.

Buildings are divided by use and occupancy into three classes based on the relative cost of a failure.

A collapsed school roof could be a major catastrophe; a collapsed hay shed is at worst a relatively minor financial loss.

Class A—permanent structures with a high degree of wind sensitivity and an unusually high degree of hazard to life and property in case of failure, such as a high-rise office building.

Class B—permanent structures with human occupancy, such as public buildings, dwellings, bunk houses.

Class C—structures having no human occupants or where there is negligible risk to human life, such as crop storage buildings, livestock production buildings, farm shops, machinery storage structures.

Recommended design loads are calculated using recurrence intervals as follows:

Class of Building	Recurrence Interval, Yr
A	100
B	50
C	25

Table 121-1. Weights of some common building materials.

Material	pcf	Weight* psf	plf
Concrete	150	...	...
Steel	490	...	...
Douglas fir	30	...	...
Oak	45	...	...
Yellow Pine	36	...	...
Insulation, per inch thickness	...	.1-.4	...
Steel roofing, 28 ga.	...	.9	...
Aluminum roofing, .024	...	.4	...
Wood shingles	...	2	...
Asphalt shingles	...	2.6	...
Softwood lumber			
1" lumber	...	2.2	...
3/8" plywood	...	1.1	...
1/2" plywood	...	1.4	...
2x4's 24" o.c.	...	0.7	...
2x6's 24" o.c.	...	1.1	...
Softwood lumber			
2x4	...	...	1.6
4x4	...	...	3.6
2x6	...	...	2.5
4x6	...	...	5.7
6x6	...	...	8.8
2x8	...	...	3.4
2x10	...	...	4.3
2x12	...	...	5.2

*pcf: pounds per cubic foot; psf: pounds per square foot;
plf: pounds per linear foot

Dead Loads

Dead loads are the weights of all materials used in the building construction, such as floor, roof, framing, and covering.

Although the dead load is normally not a major part of the total design load on a farm building, it is calculated and used in combination with the other loads. The dead load is calculated from the weight of the building materials supported by a given structural member or joint.

Three dead load cases are used for MWPS designs:

- **Low** roof = 3.5 psf; ceiling = 0.0 psf.
- **Medium** roof = 3.5 psf; ceiling = 5.0 psf.
- **High** roof = 7.5 psf; ceiling = 8.0 psf.

Low dead load includes truss, purlins, metal roofing and minimum insulation weight (machine sheds or cold livestock buildings). Medium dead load allows for the addition of a metal or plywood ceiling with insulation (warm livestock buildings). High dead load allows for a plywood roof deck with asphalt shingles, and gypsum board ceiling with insulation (residential or commercial buildings).

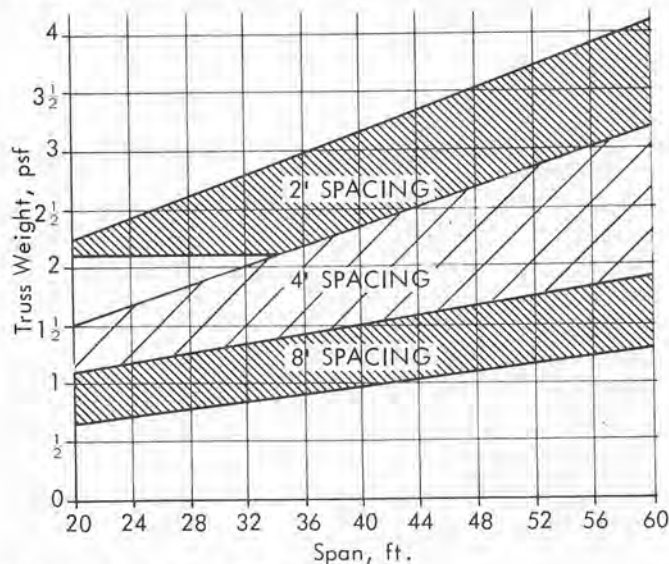


Fig 121-1. Weights of trusses.

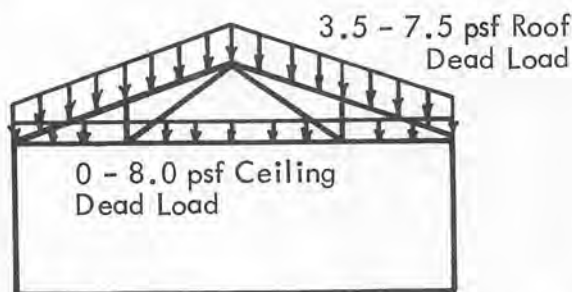


Fig 121-2. Dead load, in lb/sq ft of horizontal projection (psf-hp).

Snow and Ice Loads

Snow pack on the ground is the weight of ice, snow, and water accumulated in an undrifted condition on flat exposed ground surfaces. Snow loads are vertical loads applied to the horizontal projection of the building roof.

Snow loads vary with building class or design interval and geographical location. Most farm buildings—machinery storage, livestock production, and crop storage—are designed as Class C, 25-year recurrence interval.

Design snow loads are derived from the estimated snow pack on the ground, as determined from Weather Service records. Estimated snow pack on the ground is shown in Fig 121-3 for 25-year mean recurrence interval from ANSI A58.1-1972. The weight of the snow pack on the ground for a given location is reduced to 60% for the design snow load on a roof exposed to the wind.

Use the 60% factor for roofs that have a clear exposure to winds sufficient to remove snow and that have no projections such as parapet walls. A factor of 80% is used for roofs not exposed to the wind. The load reductions are made because less snow accumulates on a building roof than on adjacent ground.

Map values should not be used for geographic areas subjected to unusual snow pack because of elevation or other special geographic features.

Snow is assumed to be uniformly distributed over the roof surface and to act vertically downward, as in Fig 121-4. Buildings are usually first designed for snow and dead roof loads, then checked for other loads and combinations.

Exceptions to a simple uniform snow distribution are made for roof shapes subjected to drifting or sliding snow, such as saw-tooth roofs, monitors, sheds at lower elevation than roof above, or valleys, which usually require increased design snow loads.



Design snow loads

Zone I = 12 psf

Zone II = 18 psf

Zone III = 24 psf

Zone IV = 30 psf

Zone V = 36 psf

Zone VI = 42 psf

Fig 121-3. Snow load map.

ANSI A58.1-1972

Design snow load, psf = Map load x 0.6

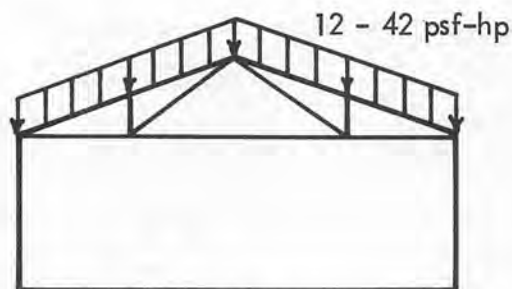


Fig 121-4. Snow load, psf-hp.

Wind Loads

Farm buildings are designed to resist all expected wind loads except those resulting from tornadoes. Velocity pressure is the pressure wind exerts on a vertical surface perpendicular to its direction if all of its energy were converted into pressure acting on the surface.

Wind pressures for design are determined by:

$$q = 0.00256 V^2$$

where:

q = basic velocity pressure, psf

V = map value of wind velocity for the extreme-mile wind in miles/hr.

h = design height of building, in ft. This is equal to the eave height H , except that

if the vertical height from eave to the extreme top of the building is equal to or greater than the eave height, then the design height, h , is the mid-elevation of the roof. All heights are measured from the average grade line.

ANSI wind velocities are from analyses of the fastest mile per year recorded at an elevation of 30'. The wind pressures include gusts and are not reduced for buildings less than 30' high.

A design speed of 80 mph for a 25-year recurrence interval includes all of the U.S., except NW and SE coastal areas. ANSI's pressures for Exposure B—suburban areas, towns, city outskirts, wooded areas, and rolling terrain—and q_F for building frames are used in MWPS plans. For flat, open country and coastal belts, use ANSI's Exposure C wind pressures.

For all members supporting 200 sq ft or less (wall girts, purlins, skin materials, etc.) the component q_F in the wind load equations should be replaced by q_P . Wind pressures on small areas may be considerably higher than those on a whole building frame. Add the internal pressures to the external pressures because internal pressures can be positive or negative in an enclosed building.

WIND LOAD COMPONENTS

RESULTANT FRAME WIND LOADS

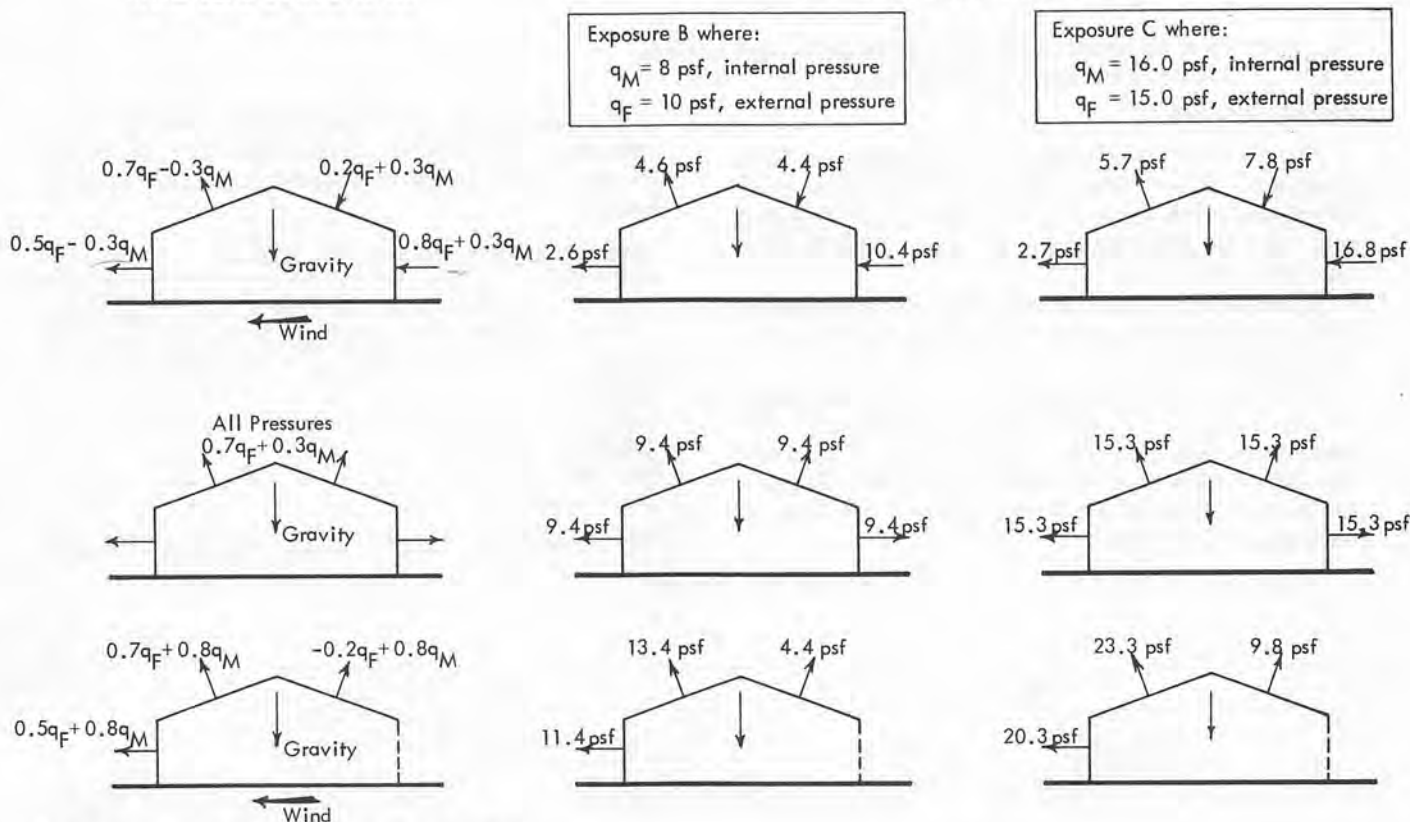


Fig 121-5. 80 mph wind loads on building frames.
 The wind is blowing from right to left.

WIND LOAD COMPONENTS

RESULTANT GIRT AND PURLIN WIND LOADS

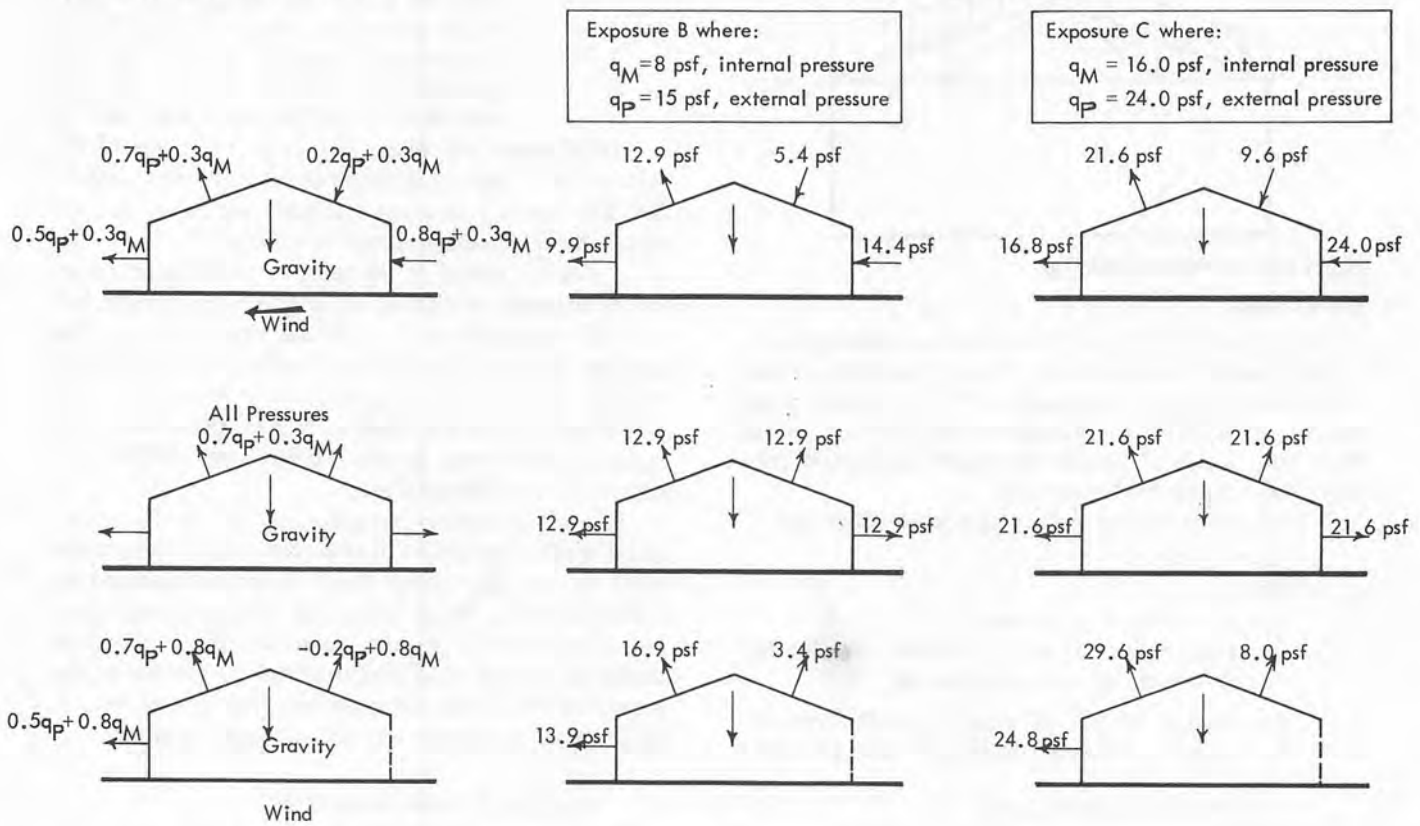


Fig 121-6. 80 mph wind loads on building girts and purlins.
 The wind is blowing from the right.

Combined Loads

Most structural elements are subjected to more than one load at a time—they are subjected to combined loads. For example, it is common to design a roof truss for dead load plus snow load and for dead load plus wind load.

The combination of dead load plus snow load is the simultaneous application of the loads in Fig 121-2 and 121-4.

Similarly, the combination of dead plus wind loads, Fig 121-2 and 121-5, determine the anchorage requirements for the truss. This combination results in a net uplift of 8-10 psf. This uplift load is resisted by the connectors provided at each end of the truss.

The snow and dead loads used in the design of structures in MWPS publications are based on 25-year snow loads and moderately liberal dead loads.

Table 121-2. Combined roof loads, psf.

	Zone I			Zone II			Zone III		
	Low	Med	High	Low	Med	High	Low	Med	High
Snow (top chord)	12	12	12	18	18	18	24	24	24
Dead Load (top chord)	3.5	3.5	7.5	3.5	3.5	7.5	3.5	3.5	7.5
Dead Load (bottom chord)	0.0	5.0	8.0	0.0	5.0	8.0	0.0	5.0	8.0
Total	15.5	20.5	27.5	21.5	26.5	33.5	27.5	32.5	39.5

CHAPTER 122 FLOOR AND SUSPENDED LOADS

Live Floor and Suspended Loads

The minimum design load on floor areas based on use of the area is listed in Table 122-1.

Table 122-1. Minimum design floor and suspended loads due to use.

Use of Area of Floor	Design Live Load psf
Cattle	
tie stall barns	70
loose housing (holding area)	80
milking parlours	70
milkrooms or milkhouses—See Note 1.	50
Sheep	30
Swine	
solid floors	40
Horses	100
Chickens—See Note 2.	
floor-housing	40
cages	
floor supported	
suspended, per length of cage row	
—full stair step double deck (no dropping boards)	75 plf
—modified stair step double deck (with dropping boards)	100 plf
—modified stair step triple deck (with dropping boards)	150 plf
Turkeys	40
Greenhouses	50
Maintenance shops—See Note 3.	70
Product storage—See Note 4.	
Machinery—See Note 3.	

1. Design floors under bulk tanks in milkrooms according to the weight of the tank plus contents.

2. Where a space is provided for the accumulation of manure for floor-housed chickens, base the design load on 60 psf/ft of depth. Base design loads for floor-supported cages on weights and support intervals.

Loads for suspended poultry cages are based on 4 row (double deck) or 6 row (triple deck) cages with 2 birds per 8 in. cage, or four 4-lb birds per 12 in. cage, and 2 in. of manure accumulated on dropping boards under upper cages.

3. See Loads for Vehicle Storage.

4. Calculate the design load for product storage on the basis of individual weights but no less than 100 psf. See chapters 123 and 124.

Slotted Floor Loads

The minimum design load on slotted floors in livestock pens is listed in Table 122-2.

Where slats are interconnected between supports so that three or more slats must deflect together, design each span of slat between support and interconnection, and between two interconnections, for the recommended load per unit length of slat. Design the full span of each slat for one-half the recommended load per unit length.

Table 122-2. Floor loads for groups of animals on slotted floors.

Livestock	Live Loads for Design of a Floor Slat Unit, per unit length of slat plf	Live Distributed Loads for Design of Slat Supports, per unit area of floor psf
Dairy and beef cattle	250	100
Dairy and beef calves to 400 lb.	150	50
Sheep	120	50
Swine—See Notes 1 & 2.		
to 50 lb	50	35
to 200 lb	100	50
to 400 lb	150	65
to 500 lb	170	70

1. An alternate requirement for slats under pigs up to 50 lb, which may dictate design, is one concentrated load of 220 lb (man + pig) located first for maximum moment, then maximum shear, in slats and slat supports.

2. Design slotted floors in farrowing pens for a single concentrated load of 250 lb located first for maximum moment, then maximum shear, in slats and slat supports.

Vehicle Storage Loads

Vehicle storage (uniformly distributed): The minimum design load on a floor area used for farm machinery with traffic limited to access and egress should be 150 psf except where the area will be occupied by either loaded farm trucks or large farm tractors (those weighing more than 13,000 lb including mounted equipment); then the design load is 200 psf.

Vehicle storage (concentrated): In the absence of specific information, the minimum design loads due to probable concentrations of loads resulting from use of a floor area are as follows:

For tractors and implements: 5000 lb per wheel.

For loaded trucks not exceeding 20,000 lb gross vehicle weight (GVW): 8,000 lb per wheel.

For loaded trucks exceeding 20,000 lb GVW: 12,000 lb per wheel.

Vehicle loading and processing: In cases where the area (minimal traffic or driveway) is to serve as a place for loading, unloading, or processing, increase minimum design loads by 50% to allow for impact or vibrations of machinery or equipment.

CHAPTER 123 LOADS IMPOSED BY STORED PRODUCTS

Silage

The National Silo Association, NSA, recommends an Equivalent Fluid Density of 20 psf for designing silos containing corn silage at 68%-72% moisture content. Lateral wall pressure is calculated using Rankine's equation:

$$L = (wh) \tan^2(45^\circ - \phi/2)$$

where: L = lateral pressure, psf
 w = silage density, psf
 h = silage height, ft
 ϕ = angle of internal friction

The NSA recommends that a maximum density, 65 psf, and a minimum angle of internal friction, 32° , be used in this equation to obtain an Equivalent Fluid Density of 20 psf.

Wall friction is estimated by:

$$f = 5.5h^{1.08}$$

where: f = wall friction, psf
 h = silage depth, ft

The wall friction equation is integrated to calculate the vertical load in lb/ft of circumference on the wall:

$$f_v = 2.64h^{2.08}$$

where: f_v = vertical wall load, lb/ft
 h = silage depth, ft

The silo footing supports the weight of the silo and equipment plus the vertical wall load created by the silage.

$$\text{Footing Bearing Area} = ([2.64h^{2.08}] \pi D + T_w) / P_a$$

where: h = silage depth, ft
 D = silo diameter, ft
 T_w = total weight of footing and silo, lb
 P_a = allowable soil bearing pressure, psf

The remainder of the silage weight, total silage weight - $(2.64h^{2.08})\pi D$, is supported by the silo floor.

GRAIN

This discussion presents distribution of probable static loads from stored grain, citations of supportive data, and limitations. Dynamic loads resulting from vibration, loading, or unloading are cited, but not predicted. Passive loads resulting from cooling of bin surface materials, increase in grain moisture content, or inward movement of bin surfaces are also not predicted.

Terminology

- Equivalent Diameter (D) = 4 (floor area) / (perimeter), which for a round bin reduces to D .
- Equivalent Fluid Density (EFD) is the apparent liquid density of a semi-fluid, and relates lateral pressures linearly with depth. The equation for EFD is simple Rankine's equation divided by the depth of grain.

$$EFD = w \tan^2(45^\circ - \phi/2) \text{ pcf}$$

where:

- w = bulk density of material
- ϕ = angle of internal friction of material, often

approximated as the emptying angle of repose.

Data on angle of repose, bulk density, and equivalent fluid density are tabulated in ASAE D-240 and D-241 and in Tables 123-2 to 123-7.

Lateral Pressure on Vertical Walls

Shallow Bins

Definition: A shallow bin has lateral wall pressures increasing nearly linearly with depth.

Depth of grain, H , is no greater than equivalent diameter, D .

Or, ratio of depth, H , to bin width, B ,
 H/B is less than $\tan(45^\circ + \phi/2)$

Lateral unit static load, $L = EFD \times H$, psf

Total lateral static load, L_t , on a unit length of wall: $L_t = EFD \times H^2/2$, plf (kg/m)

Table 123-1 gives data on the solutions of 3 conditions of shallow bin wall support.

Deep Bins

Definition: A deep bin has lateral wall pressures that increase less rapidly with depth than the linear distribution assumed in shallow bins; grain depth is greater than D , or H/B greater than $\tan(45^\circ + \phi/2)$.

The lateral unit static load on vertical walls can be approximated by Janssen's formula:

$$L = \frac{wD}{4u} (1 - e^{-4KuH/D})$$

where

- L = lateral pressure, psf
 - w = material bulk density, pcf
 - D = equivalent diameter, ft
 - K = ratio of lateral to vertical internal pressure $K = (1 - \sin\phi) / (1 + \sin\phi)$
 - ϕ = angle of repose
 - u = coefficient of friction, material on wall
- Data on u are tabulated in Tables 123-3 to 123-5 and in ASAE D242
- H = depth of fill, ft

Vertical Loads on Vertical Walls

The vertical static load, V , on a unit length of vertical wall of a shallow bin is:

$$V = u \times L_t = u \times EFD \times H^2/2, \text{ plf}$$

The vertical static load, V , on a unit length of vertical wall of a deep bin is:

$$V = \frac{wD}{4} (H + \frac{e^{-4KuH/D}}{4Ku/D} - D/4Ku) \text{ plf}$$

The vertical static load computed for a vertical wall with exposed girts can be corrected for the vertical load on the girts and the portion of the wall "shaded" by the girts. The load on the girt may be taken as L/K , psf, and the total vertical friction load, V_t , as the finite integration of the average L times u for the "unshaded" portion of each wall section.

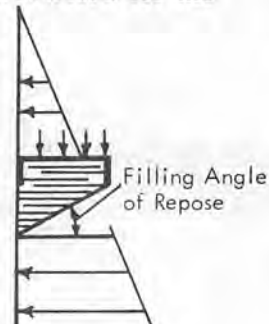


Table 123-1. Solutions for moments in shallow grain bin walls.

Units: any consistent units for weight and length.

i.e.: E, equivalent fluid density = psf

L, wall height = ft.

M, bending moment = ft. lbs.

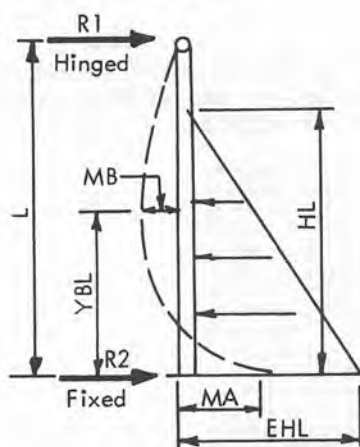
HL, depth of fill = ft.

R, reaction = lbs.

e, elastic modulus = psf

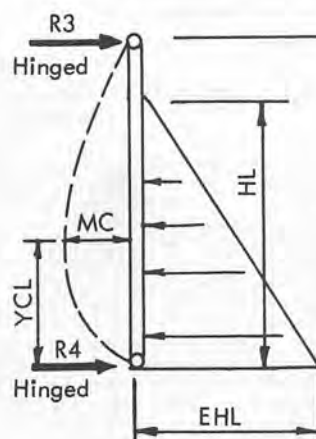
I, moment of inertia = ft.⁴ Δ , deflection = ft.**SOLUTION I**Fixed Base
Bin Partially Full

$$\begin{aligned} MA &= (\text{coeff}) \times 0.06667 EL^3 \\ MB &= (\text{coeff}) \times 0.06667 EL^3 \\ YBL &= (\text{coeff}) \times L \\ R1 &= (\text{coeff}) \times EL^2 \\ R2 &= (\text{coeff}) \times EL^2 \end{aligned}$$

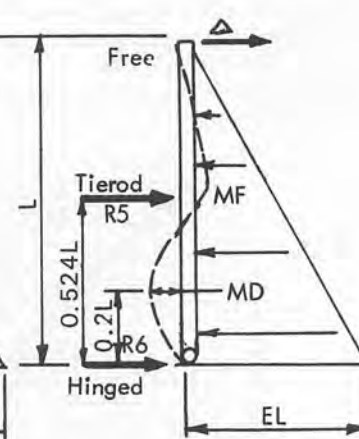
**SOLUTION II**Hinged Base
Bin Partially Full

See coefficients in table below.

$$\begin{aligned} MC &= (\text{coeff}) \times 0.06415 EL^3 \\ YCL &= (\text{coeff}) \times L \\ R3 &= (\text{coeff}) \times EL^2 \\ R4 &= (\text{coeff}) \times EL^2 \end{aligned}$$

**SOLUTION III**Free Top, Bin Full
Optimum Tie Rod Location

$$\begin{aligned} MD &= MF = 0.018 EL^3 \\ R5 &= 0.318 EL^2 \\ R6 &= 0.182 EL^2 \\ \Delta &= 0.0027 EL^5/eI \end{aligned}$$



COEFFICIENTS FOR SOLUTION I

H	MA	MB	YB	R1	R2
0.05	0.0003	0.0000	0.0488	0.00000	0.0012
0.10	0.0023	0.0002	0.0951	0.00001	0.0050
0.15	0.0075	0.0008	0.1389	0.00006	0.0112
0.20	0.0171	0.0023	0.1804	0.00019	0.0198
0.25	0.0321	0.0054	0.2195	0.00046	0.0308
0.30	0.0532	0.0104	0.2564	0.00095	0.0440
0.35	0.0810	0.0180	0.2909	0.00174	0.0595
0.40	0.1158	0.0288	0.3233	0.00294	0.0771
0.45	0.1578	0.0430	0.3534	0.00466	0.0966
0.50	0.2070	0.0611	0.3814	0.00703	0.1180
0.55	0.2632	0.0832	0.4073	0.01018	0.1411
0.60	0.3262	0.1096	0.4311	0.01426	0.1657
0.65	0.3954	0.1402	0.4530	0.01941	0.1918
0.70	0.4703	0.1748	0.4728	0.02581	0.2192
0.75	0.5504	0.2132	0.4907	0.03362	0.2476
0.80	0.6349	0.2552	0.5067	0.04301	0.2770
0.85	0.7229	0.3001	0.5209	0.05416	0.3071
0.90	0.8137	0.3475	0.5333	0.06725	0.3377
0.95	0.9064	0.3968	0.5439	0.08247	0.3688
1.00	1.0000	0.4472	0.5528	0.10000	0.4000

COEFFICIENTS FOR SOLUTION II

MC	YC	R3	R4
0.0003	0.0435	0.0000	0.0012
0.0024	0.0817	0.0002	0.0048
0.0076	0.1165	0.0006	0.0107
0.0173	0.1484	0.0013	0.0187
0.0324	0.1778	0.0026	0.0286
0.0535	0.2051	0.0045	0.0405
0.0813	0.2305	0.0071	0.0541
0.1160	0.2539	0.0107	0.0693
0.1577	0.2757	0.0152	0.0861
0.2066	0.2959	0.0208	0.1042
0.2624	0.3145	0.0277	0.1235
0.3249	0.3317	0.360	0.1440
0.3936	0.3474	0.0458	0.1655
0.4682	0.3619	0.0572	0.1878
0.5480	0.3750	0.0703	0.2109
0.6324	0.3869	0.0853	0.2347
0.7206	0.3976	0.1024	0.2589
0.8118	0.4070	0.1215	0.2835
0.9053	0.4154	0.1429	0.3084
1.0000	0.4226	0.1667	0.3333

Floor Pressure

The vertical unit static floor pressure, F , cannot exceed the weight of a unit column of the stored product; $F = w \times H$ or less, psf

The total vertical static floor load, F_t , cannot exceed the total weight of the stored product, W , less the portion of the vertical load, V_t , carried in the walls.

$$F_t = W - V_t, \text{ lb}$$

where

$$V_t = V \times (\text{bin perimeter}) = \text{total vertical wall load, lb}$$

F_t is usually applied as a pressure increasing from zero at the walls to a maximum at the center of the floor.

Fig 123-1 to 123-4 plot solutions to Janssen's equation and resulting loads and reactions. Note that they apply to a single crop density, internal friction and bin surface material.

Fig 123-5 is a nomograph convenient for solving Janssen's equations for a wide range of variables.

Static loads on sloping floors or hoppers.

Forces on the surface are:

L , unit lateral force computed from a shallow or deep bin, psf

v , unit vertical force within the grain mass,

$$v = L/K \text{ psf}$$

S , unit friction force = $u \times$ normal force

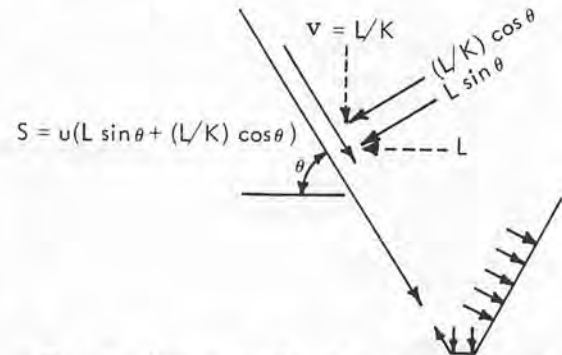
Normal component of L is $L \sin \theta$

and of v is $v \cos \theta = (L/K) \cos \theta$

$$S = u L (\sin \theta + (1/K) \cos \theta) \text{ psf (kg/m}^2\text{)}$$

where

θ = angle of hopper with the horizontal



Tensile forces in the planes of the hopper surfaces can be exerted on one surface as edge reactions from adjacent surfaces.

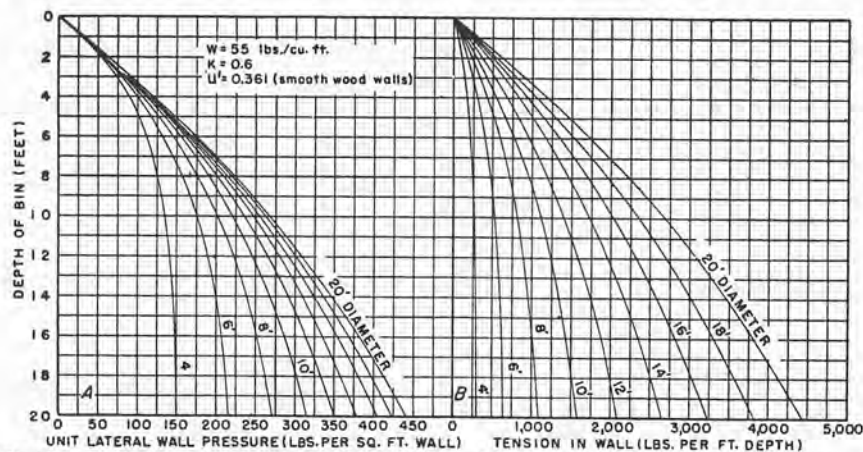


Fig 123-1. Lateral loads in cylindrical grain bins and rectangular bins of equivalent diameter:

A, Unit lateral wall pressure, psf; B, wall tension in cylindrical bins, psf.

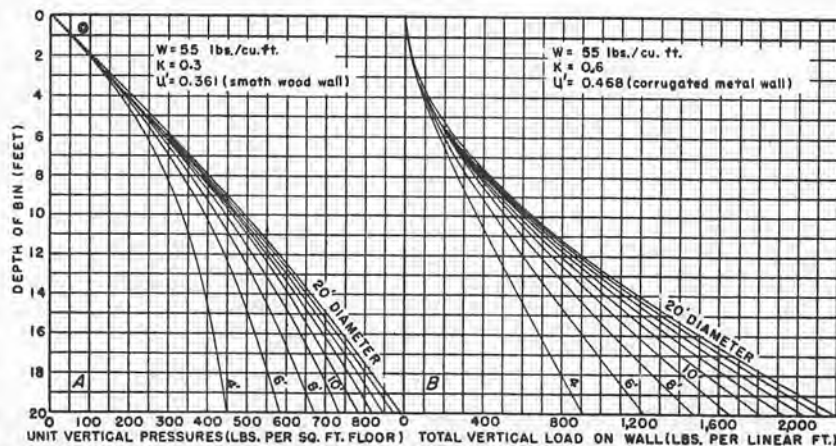
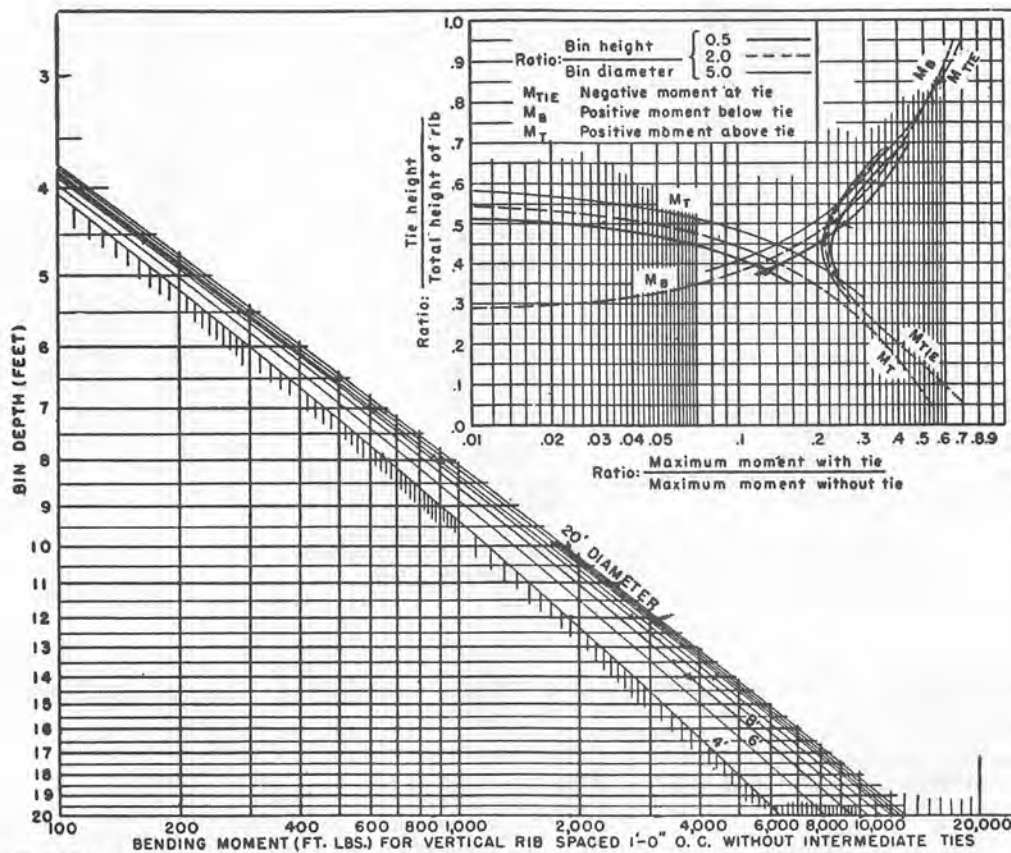
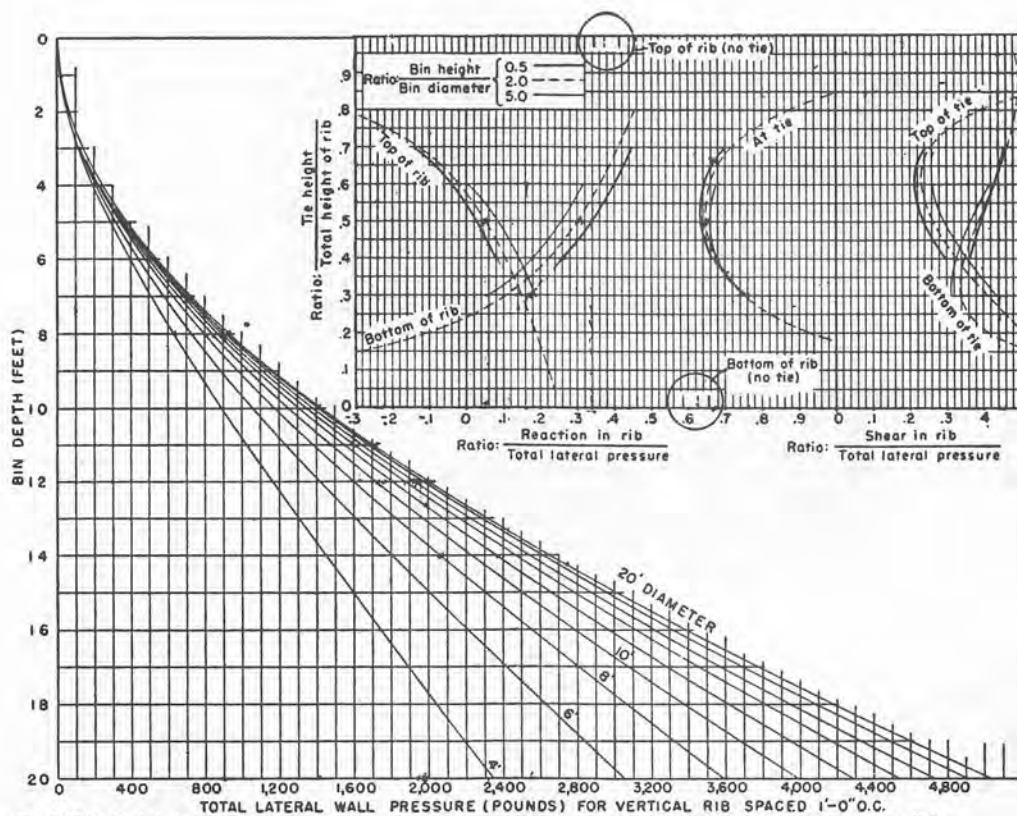


Fig 123-2. Vertical loads in cylindrical grain bins and rectangular bins of equivalent diameter: A. Floor loads, psf; B, vertical wall loads, psf.



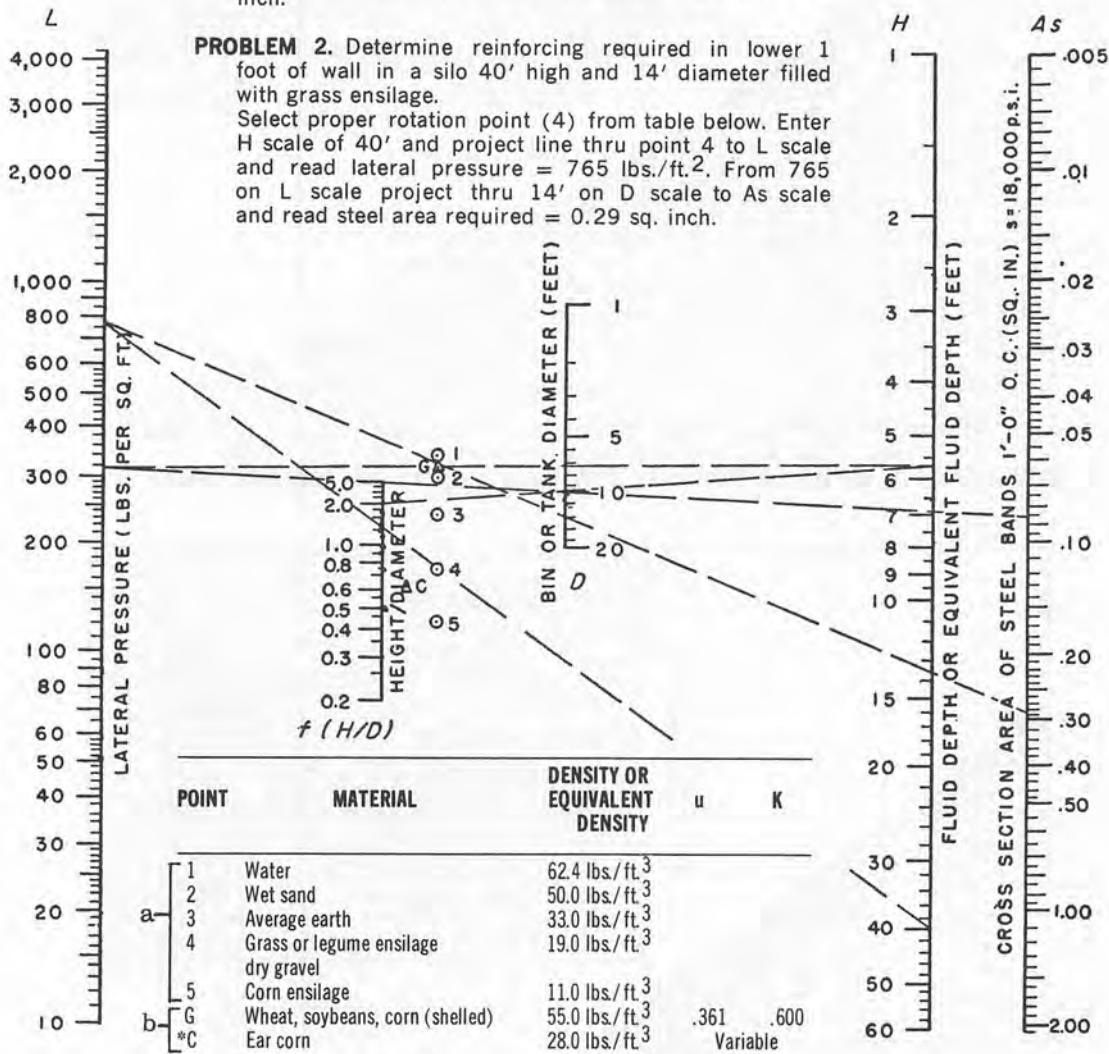
EXAMPLES

PROBLEM 1. Determine reinforcing required in lower 1 foot of wall in a bin 20' high, 10' diameter filled with wheat.

Calculate $H/D = 20/10 = 2$. Enter $f(H/D)$ scale at 2, project line thru 10' on D scale to H scale. Read value of equivalent fluid depth = 5.67'. From table below select proper rotation point for wheat (G). Project from 5.67' on H scale thru point G to L scale and read value of lateral pressure = 316 lbs./ft.². From 316 on L scale project thru 10' on D scale to As scale and read steel area required = 0.086 sq. inch.

PROBLEM 2. Determine reinforcing required in lower 1 foot of wall in a silo 40' high and 14' diameter filled with grass ensilage.

Select proper rotation point (4) from table below. Enter H scale of 40' and project line thru point 4 to L scale and read lateral pressure = 765 lbs./ft.². From 765 on L scale project thru 14' on D scale to As scale and read steel area required = 0.29 sq. inch.



*Selection of point C not determined by mathematical formula. Its use gives values for lateral pressures closely approximating available test values.

^a Water, sand, earth, gravel and ensilage pressures determined by fluid pressure formula $L = w H$ where L and H are defined as above and w = the density of a fluid which would give lateral pressures equal to those exerted by the fill material. See problem 2 above for an example of the design of cylindrical tanks or bins for these materials.

^b Grain and ear corn pressures determined by Janssen's formula

Fig 123-5. Steel reinforcing required for cylindrical storages.

Dynamic and Passive Effects

Thermal effects

Differential dimensional changes occur between bin materials and grain due to external heating or cooling; e.g. if a metal bin is filled on a hot sunny day, with nightfall the bin will shrink and cause passive pressures between the bin and the grain.

The coefficient of linear thermal expansion for corn at a moisture content of 9.3% is approximately 0.000187 in./in.-°F.

Elasticity of a grain mass may be 340 to 1000 psi.

Moisture effects

Wall pressures increase at least 6 times as moisture content rises 4%, and increases at least 10 times with a rise of 10%. Wall pressure changes with moisture content are not important to structural design of storages in which no re-wetting will occur. Flooding, or other soaking, will lead to major load increases and possible failure.

Unloading effects

Major load redistribution can result from bottom unloading. No general design formulas are known at this time, but large local pressure increases have been reported. With some materials, e.g. ground feeds, bridging over an unloading port can result in sudden release of the bridging and heavy impact loads at the port and in the lower walls of the structure.

Table 123-3. Coefficients of friction (μ) for grains.

ASAE Paper 63-628, Brubaker & Pos, Static Coefficients of Friction of Some Grains on Various Structural Materials.

Material	Moisture Content (%)	CONCRETE			WOOD				PLASTIC		METAL	
		Plastic Smooth Finish	Steel Trowel Finish	Wood Float Finish	Oak Grain Par.	Grain Perp.	Douglas Fir Grain Par.	Grain Perp.	Teflon	Polyethylene	Mild Steel C. R.	Galvanized Sheet Metal
Barley	10.7	.23	.56	.50	.23	.29	.27	.32	.17	.23	.20	.20
	12.3	.25	.55	.52	.21	.28	.28	.31	.15	.28	.25	.17
	14.3	.24	.57	.51	.21	.28	.30	.32	.13	.28	.23	.20
	16.4	.33	.62	.55	.30	.33	.37	.41	.11	.35	.21	.34
Oats	10.6	.28	.40	.43	.20	.23	.27	.29	.13	.20	.20	.22
	13.0	.34	.44	.44	.24	.25	.29	.35	.14	.24	.26	.24
	14.0	.33	.51	.42	.23	.25	.34	.36	.13	.28	.21	.18
	16.0	.29	.46	.46	.31	.31	.37	.37	.11	.31	.20	.41
	17.3	.50	.65	.64	.46	.48	.48	.50	.14	.50	.44	.32
Shelled Corn	7.5	.27	.41	.46	.24	.25	.27	.29	.17	.22	.23	.20
	9.9	.25	.59	.62	.28	.31	.31	.31	.18	.27	.20	.24
	12.2	.33	.68	.65	.26	.29	.33	.33	.16	.30	.20	.25
	13.9	.35	.64	.54	.29	.36	.37	.38	.12	.38	.24	.37
Soybeans	7.1 (7.0)	.25	.39	.39	(.29)	(.35)	.29	.31	(.23)	.25	(.32)	.21
	8.1 (10.0)	.32	.55	.52	(.33)	(.36)	.32	.37	(.21)	.32	(.39)	.21
	9.8 (11.6)	.31	.47	.37	(.34)	(.39)	.33	.31	(.19)	.29	(.41)	.18
	12.2 (15.4)	.36	.55	.52	(.42)	(.45)	.35	.44	(.17)	.43	(.45)	.20
Wheat	11.2 (9.7)	.36	.52	.51	(.30)	(.32)	.31	.35	(.19)	.27	(.33)	.10
	13.0 (11.9)	.46	.52	.55	(.28)	(.32)	.35	.38	(.17)	.35	(.33)	.14
	15.0 (13.2)	.50	.55	.51	(.29)	(.34)	.47	.46	(.15)	.39	(.32)	.27
	15.7 (15.1)	.56	.68	.69	(.35)	(.40)	.48	.50	(.12)	.45	(.38)	.33

Table 123-2. Variations in physical properties of stored crops. See attached tables and ASAE Yearbook.

The following table shows some of the variation in available data. COEFFICIENTS OF FRICTION:

Wheat on wheat			Variation
Table 1. ASAE D242	0.466		100%
AE Handbook	0.53		113%
Table 2. ASAE D242	0.532		114%
Wheat on concrete			
ISU Engr. Bul. 172	0.35		100%
Brubaker & Pos	0.36-0.69		103-192%*
AE Handbook	0.42		120%
Table 2. ASAE D242	0.400-0.425		114-121%
Table 4. ASAE D242	0.71		203%
Table 1. ASAE D242	0.444		127%
Wheat on steel			
Brubaker & Pos	0.10-0.38		26-100%*
USDA Circ. 835	0.34-0.414		90-109%
AE Handbook	0.40		105%
Table 2. ASAE D242	0.365-0.400		93-105%
Table 1. ASAE D242	0.414		109%

* Brubaker & Pos measured μ' at different moisture contents and on different materials, so ranges reflect real variations.

K, ratio of lateral to vertical pressure, wheat on concrete:

ASAE D242	0.312	100%
Reynolds, Rein. Conc.		
Des. Handbook, 1948	0.410	131%
USDA Circ. 835 & others	0.60	192%
ISU Engr. Bul. 172	0.612	196%

Table 123-4. Equivalent fluid densities for maximum weights of grains.

Grain	Angle of repose, deg*	Maximum weight per cubic foot, lb*	Equivalent fluid weight per cubic foot, lb†
Oats:			
Central United States	32	33.6	10.3
Pacific Northwest and Canada	32	35.2	10.8
Rough rice, American Pearl	36	41.6	10.8
Barley:			
Eastern	28	40.0	14.4
Western	28	43.2	15.6
Soybeans	29	46.4	16.1
Flaxseed	25	43.2	17.5
Corn, shelled	27	48.0	18.0
Rye	26	46.4	18.1
Wheat:			
Soft red winter	27	48.8	18.3
Hard red spring	28	52.0	18.8
Hard red winter	27	51.2	19.2
Durum	26	52.0	20.3
Extra heavy	26	55.0	21.5

*These values taken from "Grain Bin Requirements," USDA Circ. 835 (1950).

†Derived from Rankine's formula for lateral pressure on a smooth vertical retaining wall without surcharge; use for shallow bins only.

Table 123-5. Angles of repose and friction coefficients for clean dry grains.

These values taken from "Grain Bin Requirements," USDA Circ. 835 (1950).

Grain	Angles of repose		Average coefficients of friction of grain					
	Emptying or funneling	Filling or piling	Smooth shiny tin	Smooth Side Prest-wood ¹	Across grain of plywood	Wall boards		
						Rough side asbestos cement	Gypsum	Insulite ¹
	Deg.	Deg.						
Rough rice (paddy)	36	20	0.479	0.554	0.530	0.368	0.637	0.662
Grain sorghum	33	20	.372	.306	.294	.331	.396	.321
Oats	32	18	.445	.398	.380	.362	.442	.429
Soybeans	29	16	.368	.295	.312	.301	.379	.306
Barley:								
Two row	28	16	.404	.264	.311	.308	.389	.360
Six row	28	16	.378	.266	.287	.298	.344	.354
Wheat:								
Hard red spring	28	17	.366	.335	.298	.333	.394	.325
Hard red winter	27	16	.340	.306	.294	.323	.392	.287
Soft red winter	27	16	.356	.306	.277	.292	.372	.300
Corn	27	16	.447	.306	.302	.264	.416	.257
Wheat, Durum	26	17	.414	.321	.321	.323	.418	.311
Rye	26	17	.406	.324	.330	.354	.398	.350
Flaxseed	25	14	.372	.300	.275	.323	.319	.350
Vetch	25	14	.327	.255	.249	.242	.340	.270

¹ Mention of these brands should not be construed as an endorsement by the Department of Agriculture of either the prices or quality of these products. No discrimination is intended and no preference can be expressed or implied.

Table 123-6. Approximate storage requirements.

Material	lb/cu ft	cu ft/ton	Material	lb/cu ft	cu ft/ton
Alfalfa meal	15	134	Linseed meal	23	88
Alfalfa, chopped	12	170	Malt sprouts	15	134
Barley meal	28	72	Mixed mill feed		
Barley, whole	38	53	(bran & middlings)	15	134
Beet pulp, dried	15	134	Molasses	78	26
Bran	16	125	Molasses beet pulp	20	100
Brewers grains, dry	15	134	Meat scraps	34	59
Buckwheat bran	15	134	Oats, ground	18-20	111-100
Buckwheat middlings	23	88	Rice bran	20	100
Coconut meal	38	53	Rice polish	31	65
Concentrates, typical	45	45	Salt, fine	50	40
Corn meal	38	53	Soybean meal	42	48
Corn & cob meal, dry	36	56	Tankage	32	63
Cotton seed meal	38	53	Wheat bran	14	154
Distillers' grains, dry	15	134	Wheat feed, mixed	15	134
Gluten feed	33	61	Wheat, ground	45	46
Gluten meal	46	45	Wheat middlings (Std)	20	100
Hominy meal	28	72	Wheat screenings	27	77
Kaffir meal	27	74	Pellets, mixed feed	35-40	57-60
Lime	60	33	Pellets, ground hay	38-45	53-44

SOURCE: Based primarily on California Agricultural Circular 517.

Table 123-7. Calculated densities of grain and seeds based on weights and measures used in the department of agriculture.

Grain or Seed	Unit	Approximate net weight, lb	Bulk density lb per cu ft	Grain or Seed	Unit	Approximate net weight, lb	Bulk density lb per cu ft
Alfalfa	bushel	60	48.0	Oats	bushel	32	25.6
Barley	"	48	38.4	Orchard grass	"	14	11.2
Beans:				Peanuts, unshelled:			
Lima, dry	"	56	44.8	Virginia type	"	17	13.6
Lima, unshelled	"	32	25.6	Runners, Southeastern	"	21	16.8
Snap	"	30	24.0	Spanish	"		
Other, dry	"	60	48.0	Southeastern	"	25	19.7
Other, dry	sack	100	48.0	Southwestern	"	25	19.8
Bluegrass	bushel	14-30	11.2-24.0	Perilla	"	37-40	29.6-32.0
Broomcorn	"	44-50	35.2-40.0	Popcorn:			
Buckwheat	"	48-52	38.4-41.6	On ear	"	70*	28.0
Castor beans	"	46	36.8	Shelled	"	56	44.8
Clover	"	60	48.0	Poppy	"	46	36.8
Corn:				Rapeseed	"	50 & 60	40.0 & 48.0
Ear, husked	"	70*	28.0	Redtop	"	50 & 60	40.0 & 48.0
Shelled	"	56	44.8	Rice, rough	bushel	45	36.0
Green sweet	"	35	28.0	Rice, rough	bag	100	36.0
Cottonseed	"	32	25.6	Rice, rough	barrel	162	36.0
Cowpeas	"	60	48.0	Rye	bushel	56	44.8
Flaxseed	"	56	44.8	Sesame	"	46	36.8
Grain sorghums	"	56 & 50	44.8 & 40.0	Sorgo	"	50	40.0
Hempseed	"	44	35.2	Soybeans	"	60	48.0
Hickory nuts	"	50	40.0	Spelt (p. wheat)	"	40	32.0
Hungarian millet	"	48 & 50	38.4 & 40.0	Sudan grass	"	40	32.0
Katir	"	56 & 50	44.8 & 40.0	Sunflower	"	24 & 32	19.2 & 25.6
Kapok	"	35-40	28.0-32.0	Timothy	"	45	36.0
Lentils	"	60	48.0	Velvet beans (hulled)	"	60	48.0
Millet	"	48-50	38.4-40.0	Vetch	"	60	48.0
Mustard	"	58-60	46.4-48.00	Walnuts	"	50	40.0
				Wheat	"	60	48.0

* The standard weight of 70 lb is usually recognized as being about two measured bushels of corn, husked, on the ear, because it requires 70 lb to yield 1 bu, or 56 lb of shelled corn.

SOURCE: ASAE Data: ASAE D241.1, 1967

Potatoes

Potatoes exert pressures similar to other semi-fluids: horizontal wall pressures, vertical friction wall loads, and vertical floor loads. Loads from stored potatoes are erratic; design data are based on 80% confidence interval, and are from "Lateral Pressures on Walls of Potato Storage Units," Schaper and Herrick, USDA ARS 52-32, June 1968.

Design Loads

Table 123-8 contains basic design data.

Lateral pressures were computed from:

$$L = 17.8 + 8.52H - 0.18H^2$$

where

L = lateral pressure, psf

H = Bin depth, ft

Test bins were about 10' wide. For bins wider than 10', but with pile depth greater than or equal to width, B, multiply lateral pressures, reaction forces, and bending moments by the factor, C:

$$C = (B/10)^{1/2}$$

where

C = multiplying factor

B = bin width, ft

For bin wall frames pinned at sill and plate, maximum bending moment occurs about halfway between the midheight of the wall and the centroid of lateral pressure.

Table 123-10 presents design data for bins wider than 10' but with pile depth less than bin width.

Table 123-8. Loads from stored potatoes.

Depth of potatoes	Height of wall	Height of centroid of lateral pressure at potato pressure centroid	Total lateral pressure of potatoes at centroid	Reactions		Maximum bending moment
				At sill	At plate	
Feet	Feet	Feet	Pounds	Pounds	Pounds	Inch-pounds
4	8	1.69	136	107	29	1,600
4	10	1.69	136	113	23	1,800
6	8	2.46	247	171	76	3,180
6	12	2.46	247	197	50	4,310
8	10	3.21	384	261	123	6,150
8	14	3.21	384	296	88	8,110
10	12	3.97	544	364	180	10,440
10	16	3.97	544	409	135	13,440
12	14	4.73	723	479	244	16,170
12	18	4.73	723	533	190	20,400
14	16	5.51	919	603	316	23,560
14	20	5.51	919	666	253	29,190
16	18	6.30	1,130	734	396	32,600
16	22	6.30	1,130	806	324	39,800
18	20	7.10	1,351	871	480	43,400
18	24	7.10	1,351	951	400	52,300
20	22	7.92	1,580	1,011	569	56,000
20	26	7.92	1,580	1,099	481	66,800

Table 123-9. Loads from stored potatoes—Metric Units.

Depth of potatoes	Height of wall	Height of centroid of lateral potato pressure	Total lateral pressure of potatoes at centroid	Reaction		Maximum bending moment
				At sill	At plate	
meters	meters	meters	kg	kg	kg	kg-m
1.22	2.44	0.515	61.7	48.5	13.2	18.4
1.22	3.05	0.515	61.7	51.2	10.4	20.7
1.83	2.44	0.750	112.	77.6	34.5	36.6
1.83	3.66	0.750	112.	89.4	22.7	49.6
2.44	3.05	0.978	174.	118.	55.8	70.8
2.44	4.27	0.978	174.	134.	39.9	93.4
3.05	3.66	1.21	247.	165.	81.6	120.
3.05	4.88	1.21	247.	186.	61.2	155.
3.66	4.27	1.44	328.	217.	111.	186.
3.66	5.49	1.44	328.	242.	86.2	235.
4.27	4.88	1.68	417.	274.	143.	271.
4.27	6.10	1.68	417.	302.	115.	336.
4.88	5.49	1.92	512.	333.	180.	376.
4.88	6.70	1.92	512.	366.	147.	458.
5.49	6.10	2.16	613.	395.	218.	500.
5.49	7.32	2.16	613.	431.	181.	602.
6.10	6.70	2.41	717.	458.	258.	645.
6.10	7.92	2.41	717.	498.	218.	770.

Table 123-10. Loads from stored potatoes in wide bins.

Depth of potatoes	Height of wall	Reaction		Maximum bending moment
		At sill	At plate	
Feet	Feet	Pounds	Pounds	Inch-pounds
12	14	525	267	17,706
12	18	584	208	22,338
14	16	713	374	27,870
14	20	788	299	34,530
16	18	929	501	41,240
16	22	1,020	410	50,350
18	20	1,169	644	58,240
18	24	1,276	537	70,190
20	22	1,430	805	79,180
20	26	1,554	680	94,460

Table 123-11. Loads from stored potatoes in wide bins—metric units.

Depth of Potatoes	Height of Wall	Reaction		Maximum bending Moment
		At sill	At Plate	
meters	meters	kg	kg	kg-m
3.66	4.27	238.	121.	204.
3.66	5.49	265.	94.3	257.
4.27	4.88	323.	170.	321.
4.27	6.10	357.	136.	398.
4.88	5.49	421.	227.	475.
4.88	6.70	463.	186.	580.
5.49	6.10	530.	292.	671.
5.49	7.32	579.	244.	809.
6.10	6.70	649.	365.	912.
6.10	7.92	705.	308.	1088.

Pressures on Sloped Surfaces

Walls of bins or ventilation ducts may have sloping surfaces. The following design procedure estimates design pressures.

See Fig 123.6: Design one ft length of wall.

- Point Definition
- A Base of duct
 - B Surface of pile, vertically above point A
 - C Intersection of pile surface and wall
 - D Intersection of duct surface and wall
 - E Intersection of line AB and a horizontal through D

W = weight of potatoes above duct, lb/ft

= bulk density times area of trapezoid ABCD

L = lateral force on AE, lb/ft (kg/m), and is determined from Fig 123-7.

P = vector sum of W and L, lb

Assumptions

The lateral force on BE is equal and opposite the force on CD. No portion of the weight, W, is carried as friction load on the wall; this assumption results in a conservative design.

Pressure along duct surface, AD, is uniform.

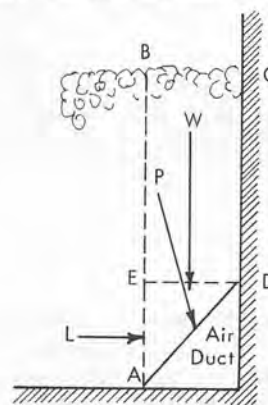


Fig 123-6. Potato pressure on sloped surfaces.

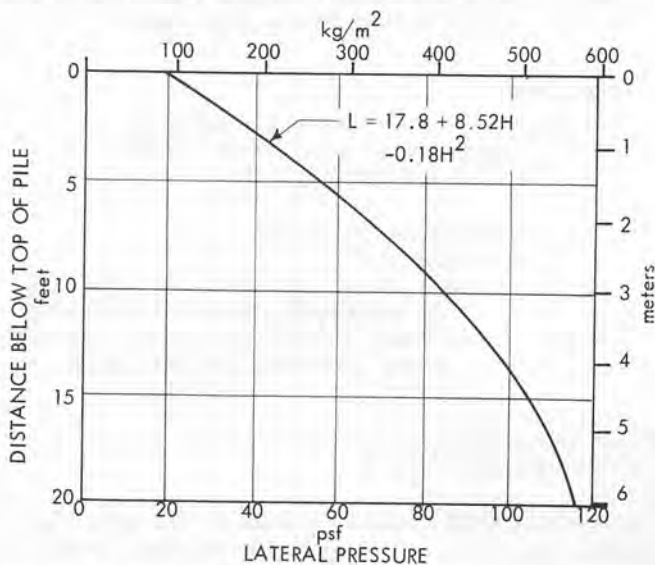


Fig 123-7. Lateral pressure of potatoes on bin walls; 10' wide bins.

CHAPTER 124 LOADS ON WASTE STORAGE TANKS

Wall Loads

Farm waste storage tanks are designed for some loads that are well known, and for some that are estimates of reasonable conditions.

The load imposed on a tank wall by contained liquids is a simple hydrostatic load, increasing uniformly from top to bottom. The pressure at any depth is:

$$\text{unit pressure} = \text{unit weight} \times \text{depth}$$

The load imposed by soil on a submerged tank depends on the soil type and moisture content in addition to its weight and the depth. MWPS tank designs are based on 60 pcf Equivalent Fluid Density; see Chapter 123. Soil loads act inward, requiring reinforcing near the inside face of the wall.

Outward loads are assumed supported by the soil and coarse-grained backfill outside the wall for depths to 8'. Arbitrarily, tanks deeper than 8' are reinforced in both faces. Deep tanks are more heavily loaded, are more apt to extend below the water table, are a greater risk if failure occurs, and are more difficult to cast with consistently high quality and well placed concrete.

MWPS tanks are not designed for saturated fine sand (110 psf/ft). This material occurs in areas of high moisture and requires special consideration for design against flotation, floor failure, and overflow.

If vehicles must drive on soil within 5' of the tank walls, a 100 psf uniform surcharge is added to the lateral load on exterior loads.

Design loads for tank walls and partitions are in Table 124-1.

Table 124-1. Lateral design loads for waste storage tank walls and partitions.

	psf per foot of depth	kg per sq m per meter of depth	Direction of Load
Walls:	60	961	outward if above ground
	15	240	inward for good drainage
	30	480	inward for moderate drainage
	60	961	inward for high water table
	110	1762	inward for saturated fine sand
Partitions:	60	961	each direction

Lid or Roof Loads

Vertical loads imposed on tanks were established by an ASAE committee before proposed floor loads for other applications were developed. Therefore there is, temporarily, some discrepancy between the following loads and those in Chapter 122.

Design loads for tank lids. 40 psf plus 25-year snow load on ground if outdoor tank lid is constructed at least 18 in. above ground level and not accessible to livestock or equipment. For snow load data refer to Chapter 121 and Fig 121-5.

150 psf if tank lid is to support livestock; 40 psf for humans or poultry.

10000 lb axle load if tank lid is accessible to tractors and tank wagons; equivalent to two 5000 lb concentrated loads 4 ft apart and oriented any direction on the tank lid.

Note: ASAE R345, Design of Farm Waste Storage Tanks, uses the word "cover" for the lid of a tank. Unfortunately this word also refers to the concrete protection over reinforcing steel, so the word "lid" or "roof" is used in recent MWPS publications.

130 DESIGN

CHAPTER 131 DESIGNING WITH LUMBER*

Because strength is a function of moisture content, and member selection is based on both the size of the member and its strength, three elements are established before designing in wood: moisture content during use, size during use, and quality or allowable stresses.

Moisture content

A green log contains free water in the cell cavities and intercellular spaces, and absorbed water in the capillaries of the walls of wood elements such as fibers and ray cells. The fiber saturation point (about 30% moisture for all species) is reached when all free water is removed and all absorbed water remains. For Douglas fir or southern pine, shrinkage occurs below 20% at about 1/5% of green size per 1% drop in moisture in edge grain, and 1/4% per 1% in flat grain.

Moisture content of the wood during use affects not only the size and strength of the lumber, but also strength and perhaps durability of glue joints and performance of nails and other hardware fasteners.

There has been no limitation for many years on the moisture content of lumber designed under established stress grades, except that the moisture content, by implication, must be below saturation (about 30%).

Fig 131-1 relates relative humidity, dry bulb temperature, and equilibrium moisture content of wood. Even in livestock buildings, it is unlikely that relative humidities will remain high enough long enough to elevate the moisture content of lumber appreciably above 15%.

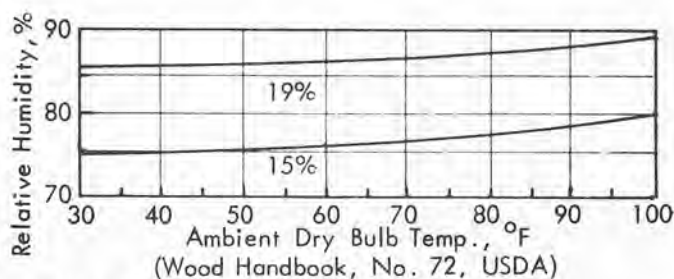


Fig 131-1. Equilibrium moisture content of wood.

Grading rules now increase allowable stresses for limited moisture content, and set the thickness of 2" nominal lumber at 1-1/2" for lumber dried to below 19% before milling.

The grading rules published by the Western Wood Products Association (1970) establish three moisture levels with corresponding stresses and moduli of elasticity. The grading rules of the Southern Pine Inspection Bureau (1970) require kiln drying of all lumber to at least 19%.

Allowable Stresses

Sample stresses for lumber grades and species commonly available are in Table 514-1. Engineers adjust these values for moisture content, duration of load, size and shape of cross section, fire-retardant treatment, and special conditions of shear and bearing.

Design

The design of wood members is rational—that is, principles of materials and how they behave are used to develop equations from which members and fasteners can be selected. The following derivation illustrates the procedure for a simple case.

Design Example—Simple Beam

When a beam is loaded, it bends enough to support the load. Picture a 2x4 notched out, pinned at the centerline, and with 2 springs inserted near the outer edges. As the 2x4 bends, the top spring shortens—compression—and the bottom spring stretches—tension. The change in length of the springs is proportional to the load; the bigger the load the bigger the change in length of each spring. Note that springs close to the hinge have little change in length.

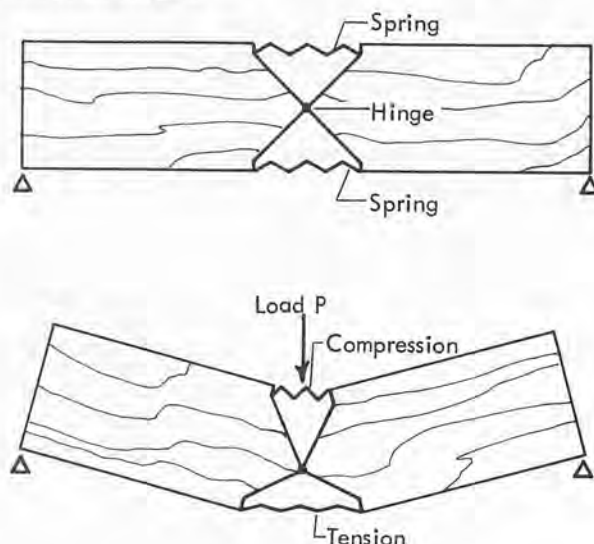


Fig 131-2. Schematic beam.

In a wood beam, wood fibers act like springs. In a solid 2x4, the top fibers shorten a lot; near the centerline they shorten a little. The same is true of the tension fibers.

The amount of compression is represented by the forces above the beam's centerline—a triangle of forces extending across the width. The amount of tension is below the centerline. C and T are at the

*Reference: National Design Specifications for Stress-Grade Lumber and its fastenings. NFPA.

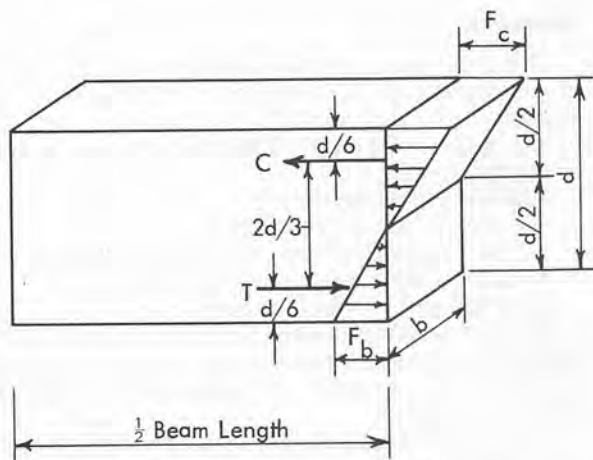


Fig 131-3. Internal forces at the center of a beam.

centroids of their forces, $\frac{1}{3}$ of the depth of the triangle, or $d/6$ from the outer edges of the 2x4.

$$T = C = (F_b \times b \times d/2) / 2 = F_b bd/4$$

T and C are a couple, that is, 2 equal forces acting in opposite directions that tend to rotate the member. If you pushed-pulled on a 2x4 on a table, you would make the 2x4 rotate.

The couple inside the lumber is what resists the external forces on the beam. The load P is resisted by the two reactions, each $P/2$. There are two couples outside the beam: the forces $P/2$, $L/2$ apart.

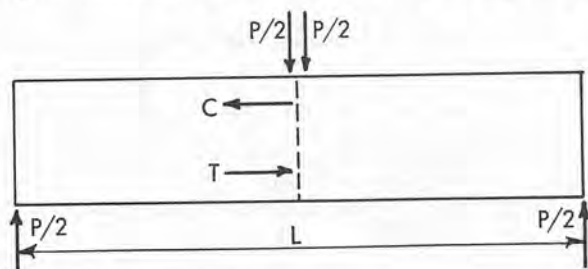


Fig 131-4. External beam forces.

The couple force times the couple distance is "bending moment," or moment, M. The external moment is:

$$M_e = P/2 \times L/2 = PL/4$$

The internal moment is:

$$M_i = T \times 2d/3 \text{ (can use T or C)}$$

If the beam is in equilibrium (not moving or breaking), the internal couple is resisting the external couple, and the two couples are equal.

$$M_e = M_i$$

$$PL/4 = T \times 2D/3$$

$$\text{But, } T = F_b bd/4$$

$$PL/4 = F_b bd/4 \times 2d/3$$

$$PL/4 = F_b bd^2/6$$

$PL/4$ is the moment due to load for a single load in the center of a simple beam. Moments for other cases are given in Chapter 511.

F_b is the allowable bending stress, is a property of the material the beam is made of, and is given for some lumber species and grades in Table 514-1.

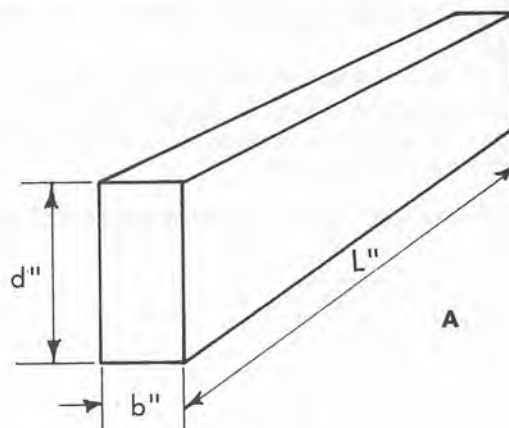
$bd^2/6$ is a property of the shape of the beam's cross section, and is given for various lumber sizes in Table 514-2 in the column headed "Section Modulus, S".

$$\text{Therefore, } M = F_b S, \text{ or } S = M/F_b$$

Usually, you know the lumber type, span, and load. Calculate the bending moment, M. Calculate the section modulus required: $S = M/F_b$. Find a member with an adequate S. Note: S is in in^3 , F_b is psi, M is inch-lb. The load, w, is often lb/ft; divide it by 12. Use beam length in inches.

Design Symbols

Section properties:



$$A = \text{area, in}^2, b \times d$$

$$I = \text{moment of inertia around neutral axis.}$$

$$= \frac{bd^3}{12}, \text{ in}^4$$

$$c = \text{distance from neutral axis to extreme fiber, in.}$$

$$S = \text{section modulus}$$

$$= \frac{I}{c} = \frac{bd^2}{6}, \text{ in}^3$$

$$S_f = \text{shear factor}$$

$$= 2bd/3, \text{ in}^2$$

Load properties:

$$M = \text{maximum bending moment}$$

$$V = \text{total vertical shear or end reaction, lb.}$$

Working stresses (psi):

$$F_b = \text{bending}$$

$$F_c = \text{compression } \parallel \text{ to grain}$$

$$F_{c\perp} = \text{compression } \perp \text{ to grain}$$

$$F_t = \text{tension } \parallel \text{ grain}$$

$$F_v = \text{horizontal shear}$$

$$E = \text{modulus of elasticity}$$

Design Equations—simple rectangular members

The following sections are abstracts, and are not intended for detailed design.

Beams

$$F_b = Mc/I = M/S = \text{bending stress}$$

Beware of notches and defects near area of maximum moment, M , that reduce S and increase F_b .

$$F_v = \frac{VS_f}{I} = \text{horizontal shear stress}$$

In computing V , neglect loads within d of the support.

$$F_{c\perp} = \text{load, lb, / wood surface area, in.}^2$$

Columns—rectangular members

additional variables

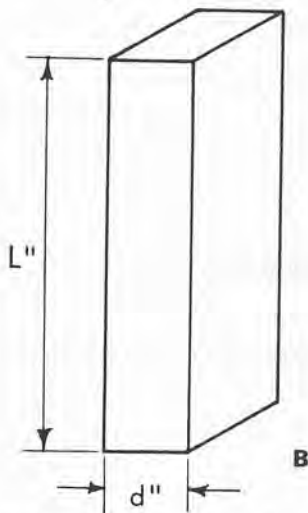
d = least side dimension

$$F_c = \text{allowable compression parallel to grain, Table 514-1.}$$

$$F'_c = \text{allowable compression adjusted for } L/d$$

L = unsupported length of simple columns, or o.c. spacing of supports of continuous or spaced columns, in.

$$P/A = \text{unit stress, not to exceed the lesser of } F_c \text{ and } F'_c$$



$$L/d \leq 50$$

$$F'_c = 0.3E/(L/d)^2$$

Combined stresses, bending+ compression.

When a member is subjected to both bending and axial loads, their total effect must not exceed the strength of the member. The ratio of design stress in bending over maximum flexure stress is a measure of the proportion of total strength used in bending. Similarly, the proportion of total strength used in compression is the axial stress over the allowable compression stress adjusted for L/d . The sum of the stress effects must not exceed 1.0.

$$\frac{P/A}{F'_c} \pm \frac{M/S}{F_b} = 1.0 \text{ or less}$$

Note: F'_c cannot exceed F_c

Deflection

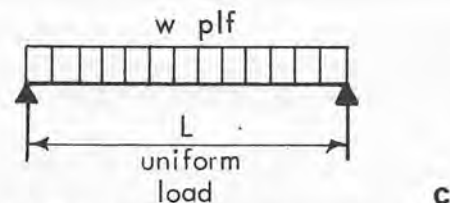
A beam bends or yields under load. The amount of distance yielded that returns after the load is removed is "deflection." Any yielding remaining in the unloaded beam is "permanent set," a typical property of wood.

Excess deflection can:

- break glass or crack plaster
- interfere with doors or movable windows
- make a floor seem too "springy"
- interfere with good appearance

Deflection is often limited to span/360 for members supporting glass or plaster, or where appearance is especially important, or to span/180 in many farm service buildings.

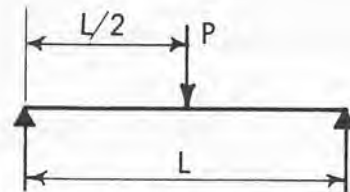
Deflection is calculated from the dimensions and properties of the member, and from the loading system.



$$M = wL^2/8 \text{ in-lb, maximum at center;}$$

$$V = wL/2 \text{ lb, at ends}$$

$$\text{Defl} = 5wL^4/(384EI), \text{ in., maximum at center.}$$



$$M = PL/4 \text{ in-lb, maximum at center}$$

$$V = P/2 \text{ lb, at ends}$$

$$\text{Defl} = \frac{PL^3}{48EI} \text{ in., maximum at center}$$

Lateral support of beams is based on their depth-to-thickness ratios, using nominal dimensions.

2:1 no support needed

3:1 support ends

4:1 hold member in line as in a well-bolted chord member in a truss

5:1 hold one edge in line

6:1 install bridging up to 8' o.c.

7:1 hold both edges in line

If a beam supports both bending and compression, hold one edge in line (e.g. rafters and diagonal sheathing) at a ratio of 5:1. If dead load induces tension on the under side of the rafters, the ratio may be 6:1.

Depth of a truss upper chord or arch may be used in L/d if supported by roof joists, not purlins, between the chords.

Depth may also be used if roof joists or plank are on top of the chord or arch, and if securely fastened to the chord and to blocking between the joists.

CHAPTER 132 PLYWOOD SELECTION *

Plywood is made from about 70 wood species that are classified into 5 groups. Group 1 species are the strongest and Group 4 species are the weakest.

General

Type

Plywood type is determined by the kind of glue and the veneer grades used to make a panel. **Exterior** is made with waterproof glue and restricted grades of veneers. **Interior** is made with water-resistant or waterproof glues and lower veneer grades for inner and back plies than in Exterior type.

Grades

Within each plywood type there are sanded appearance grades determined by the veneer grade (N, A, B, C or D) used for the face and back of the panel. Engineered grades are usually unsanded and are designed for construction applications where strength properties are important. C-C Exterior is the most commonly used plywood for farm building and equipment construction. C-DX (C-D Interior type with exterior glue) may also be used for applications where it is protected from high moisture conditions. Structural I and II grades may be either Interior or Exterior type, but are manufactured only with exterior glue. Structural I grades have Group 1 woods but Structural II grades may have Group 1, 2, or 3 woods. All unsanded engineered grades $\frac{7}{8}$ " thick or less carry an Identification Index number in the grade-trademark. Sanded or touch-sanded grades carry a Group number.

Identification Index

The Identification Index is a pair of numbers, separated by a slash, on unsanded engineered grades that tells the panel's basic bending strength. The number on the left is the maximum recommended spacing, in inches, for roof decking supports with the face grain across the supports. The number on the right is the recommended maximum spacing, in inches, for residential subflooring supports with the face grain across the supports. Example: An Index of 32/16 means the panel is for roof decking with supports up to 32" o.c. and for subfloors on supports up to 16" o.c. An "O" on the right of the slash means the panel should not be used for subflooring. Specify wall sheathing by both thickness and Identification Index.

Identification Index and Farm Buildings

Consider human occupancy factors, even in structures built outside building code jurisdiction.

*Chapter prepared from publications of the American Plywood Association.

Table 132-1. Identification Indexes for unsanded grades.

Panels thicker than $\frac{7}{8}$ " are identified by Group number.

Thickness inch	C-D Int C-C Ext		
	Group 1 & Structural I	Group 2 or 3 & Structural II ^a	Group 4 ^b
5/16	20/0	16/0	12/0
3/8	24/0	20/0	16/0
1/2	32/16	24/0	24/0
5/8	42/20	32/16	30/12 ^c
3/4	48/24	42/20	36/16 ^c
7/8	-	48/24	42/20

^a Some special panels with Group 2 outer plies or Structural II panels with Group 1 faces carry Group 1 Identification Indexes.

^b Some special panels with Group 4 outer plies carry the Identification Index numbers for Group 3 panels.

^c Check local availability.

If the life hazard exposure is low, such as in crop storages, animal housing, or service buildings, greater support spacings than indicated by the Identification Index may be used without reducing the structural adequacy of the building.

Use Recommendations

Select plywood based on strength or appearance as given in the tables and recommendations in this chapter.

Exterior type plywood (waterproof glue) is recommended for farm buildings and equipment, both inside and outside. The C-C grade of Exterior plywood is the most common with C-DX grade as an alternate where moisture content will be less than 16%. C-DX may also be used for sheathing if it is not exposed to high moisture or the weather for an extended time. Fig 132-1 relates relative humidity, dry bulb temperature, and equilibrium moisture content of wood. Even in livestock buildings, it is unlikely that relative humidities will remain high enough long enough to elevate the moisture content of lumber appreciably above 15%.

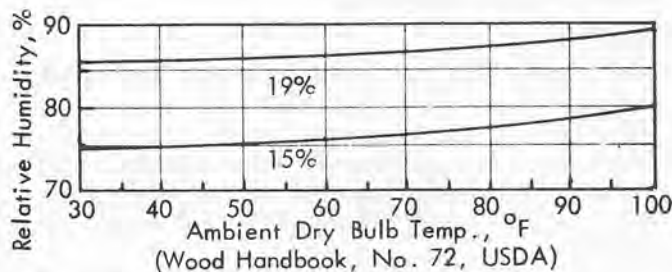


Fig 132-1. Equilibrium moisture content of wood.

Apply plywood panels with the face grain perpendicular to the supports for maximum strength and stiffness. When installing roof decking, wall sheathing, or subflooring leave $\frac{1}{16}$ " between panel ends and $\frac{1}{8}$ " between panel edges to allow for slight expansion. Double these spacings if wet or humid conditions are expected. Tongue and groove or shiplapped plywood may be installed with only $\frac{1}{16}$ " between panel edges.

Nailing

Use common nails in sheathing and subflooring. Use finished or casing nails in paneling and siding. Use ring-shank nails in underlayment and where extra holding power is needed. Galvanized nails are recommended. Nail no closer than $\frac{3}{8}$ " to panel edges. Table 132-2.

Table 132-2. Recommended minimum nailing for plywood.

<u>Plywood</u>	<u>Nail size</u>	<u>Nail spacing on supports</u>	
		<u>Panel edges</u>	<u>Intermediate</u>
Roof and wall sheathing, paneling			
1/4"	4d	6"	12"
5/16"-1/2"	6d	6"	12"
5/8"-7/8"	8d	6"	12"
When supports are 48" o.c. space all nails 6" o.c.			
Sub-flooring			
1/2"	6d	6"	10"
5/8"-7/8"	8d	6"	10"
1"-1 1/4"	10d	6"	6"
If resilient flooring is to be applied without underlayment, set nail heads 1/16"; use ring-shank nails.			
Underlayment			
1/4"-1/2"	3d	6"	8" each way
5/8"	4d	6"	8" each way
Shingles to plywood			
Asphalt	3/4" or 7/8"-12 ga., 3/8" head nails		
Wood	3d		
Asbestos	1 1/8"-12 ga. aluminum, screwthreaded shank, needlepoint		

Agricultural Buildings

Siding

Use only Exterior type panels: C-C Ext, MDO, or 303. Avoid C-DX panels, which may delaminate when permanently exposed to the weather. Finish siding with a 2 coat acrylic latex exterior paint system or a stain for textured panels. MDO panels hold paint much better than do C-C Ext or 303 siding panels.

Table 132-3 gives recommendations for plywood siding applied directly to studs or girts.

Table 132-3. Farm siding applied directly over supports.

See also Tables 132-15 and 16.

Stud spacing	Utility buildings		Premium construction	
	Plywood thickness		Plywood thickness	
	Vertical panels	Horizontal panels	Vertical panels	Horizontal panels
16" o.c.	5/16"	1/4"	3/8"	3/8"
24" o.c.	3/8" ^a	5/16"	1/2"	3/8"
32" o.c.	b	3/8"	b	1/2"
48" o.c.	1/2" ^c	1/2"	3/4" ^c	5/8"

a For interior walls 1/4" sanded panels may be used over supports 24" o.c.

b Not modular to most common 48" panel width.

c Cross blocking 4' o.c. between frames.

Ceilings

Typical ceilings are illustrated in Fig 132-2. A plywood ceiling can brace the bottom chords of trusses and support insulation above it.

An alternative to $\frac{1}{2}$ " T & G is square edge plywood with blocking or 2 plyclips along each panel edge. Also satisfactory is $\frac{3}{8}$ " plywood on trusses 32"-48" o.c. with 2x4 blocking at each edge.

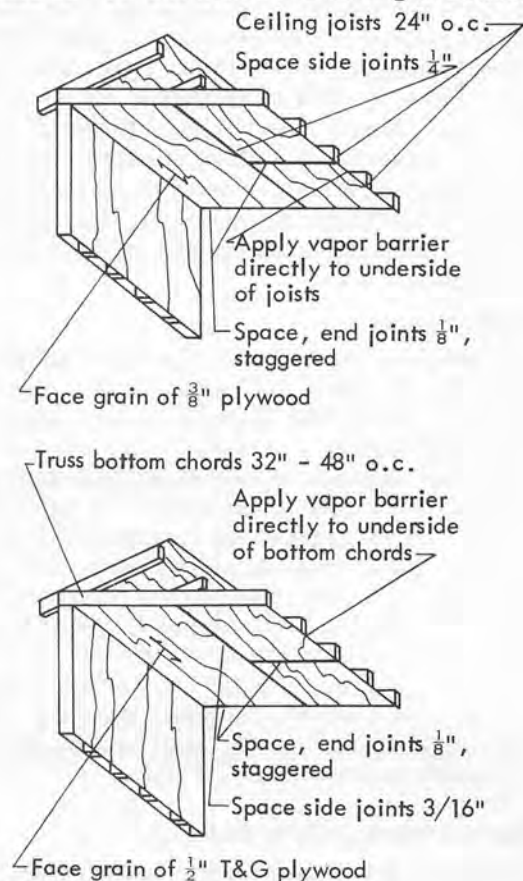


Fig 132-2. Plywood ceilings.

Roofs

Minimum Identification Indexes for roof sheathing in Table 132-4 are based on snow loads of 15, 25, 35, and 45 psf for Zones I, II, III, and Residential uses respectively.

Apply plywood sheathing with its face grain across the supports. Use plyclips or blocking to prevent differential edge deflection when $\frac{1}{2}$ ", $\frac{5}{8}$ ", and $\frac{3}{4}$ " panels span more than 28", 32", or 36" respectively.

Granular Storages

Table 132-5 gives safe load data for plywood floors or other structural applications.

Tables 132-6 and 132-7 give recommendations for shelled corn or wheat bin floors and walls. Install the plywood with face grain across the supports; use nail size and spacing given in Table 132-1.

Table 132-4. Identification Indexes for farm roof sheathing.*

Snow Load	Support spacing							
	16" o.c.		24" o.c.		32" o.c.		48" o.c.	
	Ident. Index	Panel thickness	Ident. Index	Panel thickness	Ident. Index	Panel thickness	Ident. Index	Panel thickness
Zone I	12/0	5/16"	16/0	5/16", 3/8"	24/0	3/8", 1/2"	32/16	1/2", 5/8"
Zone II	12/0	5/16"	20/0	5/16", 3/8"	24/0	3/8", 1/2"	42/20	5/8", 3/4", 7/8"
Zone III	12/0	5/16"	20/0	5/16", 3/8"	32/16	1/2", 5/8"	42/20	5/8", 3/4", 7/8"
Residential	16/0	5/16", 3/8"	24/0	3/8", 1/2"	32/16	1/2", 5/8"	48/24	3/4", 7/8"

* C-C EXT grade applied with face grain across supports.

Table 132-5. Safe loads for plywood panels.

See also Tables 132-8 to 10.

Support spacing inch	Identification Index	Panel thickness inch	Safe load psf ^a	Safe load psf ^b
12	24/0 ^c	3/8	220	265
		1/2		
	32/16	1/2	335	435
		5/8		
	42/20	5/8	475	590
		3/4		
	48/24	7/8	675	780
		3/4		
16	24/0 ^c	3/8	120	145
		1/2		
	32/16	1/2	185	240
		5/8		
	42/20	5/8	290	330
		3/4		
	48/24	7/8	380	440
		3/4		
24	32/16 ^c	1/2	80	105
		5/8		
	42/20 ^c	5/8	125	145
		3/4		
	48/24	7/8	165	190
		3/4		

^a C-D Int w/exterior glue or C-C Ext plywood. Face grain across supports, deflection limited to span/180.

^b If marked Structural I.

^c Limited to light concentrated loads, such as foot traffic, and to uniform loads specified. For other conditions, specify greater Identification Index.

Table 132-6. Identification Index for shelled corn or wheat bin floors.

Support spacing inch	Maximum depth of level fill feet	Identification Index	Panel thickness inch
12	8	32/16	1/2
			5/8
	12	42/20	5/8
			3/4
	16	48/24	7/8
			3/4
	6	42/20	5/8
			3/4
	8	48/24	7/8
			3/4
	10	48/24*	3/4
			3/4

* If stamped Structural I.

Table 132-7. Identification Index for shelled corn or wheat bin side walls.

Support spacing inch	Maximum depth of level fill feet	Identification Index	Panel thickness inch
12	8	12/0	5/16 5/16
	10	20/0	5/16 3/8
	16	24/0	3/8 1/2
	20	32/16	1/2 5/8
			3/8
16	8	24/0	1/2 3/8
	12	32/16	1/2 5/8
	20	42/20	5/8 3/4 7/8
			1/2
20	8	32/16	5/8 1/2
	12	42/20	3/4 7/8
	20	48/24	3/4 7/8
			5/8
24	8	42/20	3/4 7/8
	10	48/24	3/4 7/8
	12	48/24*	3/4

* If stamped Structural I.

Table 132-8. Plywood and support spacing.

Pressure zone	Identification Index	A-C Ext Group 1 inch*	Support spacing inch	Approx. pressure psf
14	24/0	3/8	24	50
13	42/20	5/8	32	65
12	32/16	1/2	24	75
11	48/24	3/4	32	80
10	24/0	3/8	16	110
9	42/20	5/8	24	115
8	48/24	3/4	24	145
7	32/16	1/2	16	165
6	24/0	3/8	12	195
5	42/20	5/8	16	255
4	32/16	1/2	12	295
3	48/24	3/4	16	325
2	42/20	5/8	12	450
1	48/24	3/4	12	575

* For each step the group number of sanded plywood departs from Group 1, take one step down to the next smaller zone number. For example, if Group 3 plywood is used, and the applicable figure shows Zone 11, use the plywood and support spacing shown for Zone 9.

Shallow bins

Bins with a height $< \tan(45 + \phi/2) \times \text{width}$ are considered "shallow", where ϕ is the angle of internal friction (emptying angle of repose). Table 123-4 includes the emptying angle of repose, maximum density, and equivalent fluid density of grain.

Determine the floor load in a shallow grain bin by multiplying the depth of fill by the maximum grain density. Select an adequate Identification Index from Table 132-5.

For the lateral wall pressure, multiply the equivalent fluid density by the depth below the surface. Select an adequate Identification Index from Table 132-5.

Deep bins

The lateral pressure exerted by a granular material depends on:

- The material stored.
- The height of the material above the point being considered.
- The equivalent bin diameter.

For round bins, equivalent diameter = bin diameter. For rectangular bins, where the length is more than 1.5 times the width, it is the bin width. For rectangular bins with length less than 1.5 times width:

$$\text{Equivalent diameter} = (4)(\text{floor area})/\text{perimeter}$$

Fig 132-3 and 132-4 show the required "Pressure Zone" for various combinations of material depth and equivalent diameter.

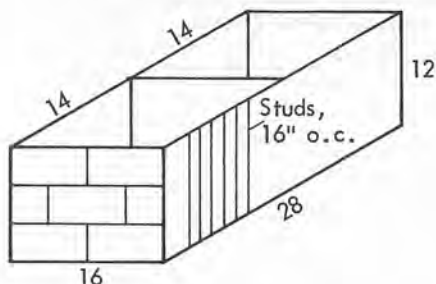
The figures apply to other materials with similar properties. Note that in the figures, grain depths increase toward the **bottom**, and that the **lowest**-numbered zones produce the **highest** pressures. They also can be used to design shallow bins.

Each of the 14 zones corresponds to a particular support spacing and plywood description shown in Table 132-8. Sheathing is described by Identification Index; sanded plywood is described by species group and thickness.

To select the plywood thickness:

- Determine the equivalent diameter of the bin.
- Select the chart that applies to the material stored, Fig 132-3 and 132-4.
- Use the equivalent diameter and material depth to find the pressure zone from the chart.
- Select the plywood description and maximum support spacing from Table 132-8.

Example: Select plywood walls for a shelled corn storage 16' wide, 28' long, and 12' high. A center partition, perpendicular to the 28' wall, divides the building into bins of equal size. Plywood will be installed with its face grain across vertical studs spaced 16" o.c.



Equivalent diameter:

Each 16'x14' bin is less than 1.5 times as long as it is wide:

$$\begin{aligned} \text{Equivalent diameter} &= \frac{4 \times \text{floor area}}{\text{perimeter}} \\ &= \frac{4(14 \times 16)}{2(14 + 16)} = 14.9' = 15' \end{aligned}$$

Because the bin will store shelled corn, find the Pressure Zone from Fig 132-3. For a 15' equivalent diameter and 12' depth of grain, Fig 132-3 shows Zone 5. Referring to Table 132-8, Zone 5 requires a 42/20 Identification Index or $\frac{5}{8}$ " A-C EXT Group 1 with studs 16" o.c.

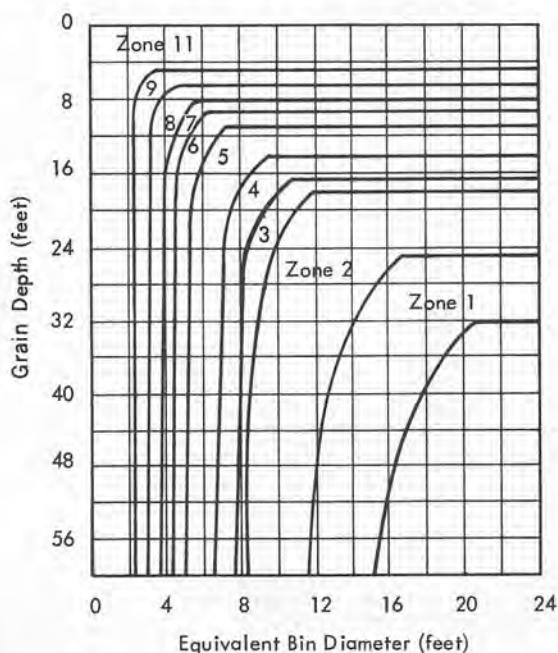


Fig 132-3. Shelled corn, wheat, flaxseed, rye; 48 pcf.

Since the pressure decreases with increasing heights above the bottom of the bin, more economical plywood panels can be used toward the top. For an 8' depth and 15' equivalent diameter, Fig 132-3 shows Zone 8. For Zone 8, Table 132-8 gives plywood requirements only for supports 24" o.c. Since the supports are spaced 16" o.c., check the next-lower-numbered zone giving the plywood requirements for a 16" support spacing. In this case, Zone 7 shows 32/16 or $\frac{1}{2}$ " A-C EXT Group 1.

For a 4' depth, Fig 132-3 shows Zone 11. Table 132-8 shows a plywood thickness for this zone based on a 32" support spacing. Select 24/0 or $\frac{3}{8}$ " A-C Ext Group 1 as indicated for Zone 10.

A similar procedure can be used to determine the allowable support spacing for a given zone and plywood thickness or Identification Index.

Install the plywood on the inside of the wall framing. If the plywood is installed on the outside of the framing, the fasteners will be loaded in withdrawal and require special design.

Commercial and Residential Buildings

Roof Decking

Allowable uniform loads for plywood roof decking are given in Table 132-9, which is based on plywood installed with face grain perpendicular to its supports.

Building roofs receive occasional foot traffic sufficient to cause differential deflection at unsupported panel edges. If edge-support is desired, it can be achieved with Plyclips, tongue-and-groove plywood joints, or lumber blocking.

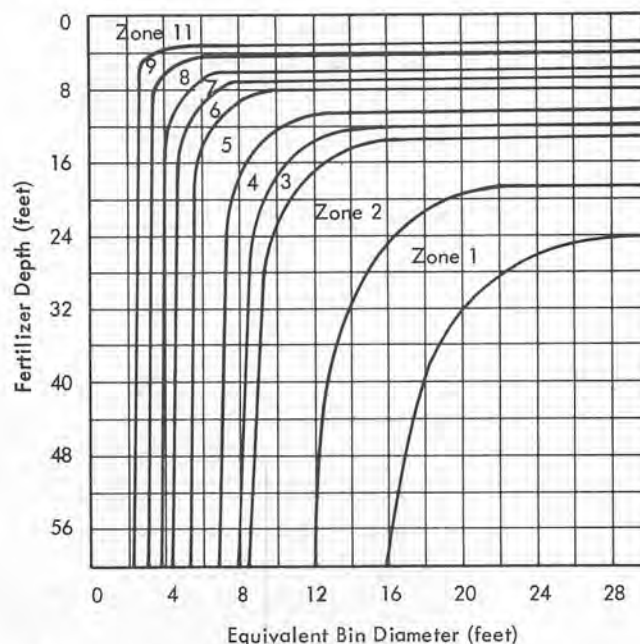


Fig 132-4. Fertilizer, 70 pcf.

Table 132-9. Commercial roof decking—face grain across supports.^{a,c}

5 psf dead load assumed.

Panel Ident. Index	Plywood thickness inch	Max. span inch	Unsupported edge-max. length (a)(b) inch	Allowable uniform live loads (psf)										
				Spacing of supports center to center (inches)										
				12	16	20	24	30	32	36	42	48	60	
12/0	5/16	12	12	150										
16/0	5/16, 3/8	16	16	160	75									
20/0	5/16, 3/8	20	20	190	105	65								
24/0	3/8, 1/2	24	24	250	140	95	50							
32/16	1/2, 5/8	32	28	385	215	150	95	50	40					
42/20	5/8, 3/4, 7/8	42	32		330	230	145	90	75	50	35			
48/24	3/4, 7/8	48	36			300	190	120	105	65	45	35		
2-4-1	1-1/8	72	48				390	245	215	135	100	75	45	
1-1/8" Grp. 1&2	1-1/8	72	48				305	195	170	105	75	55	35	
1-1/4" Grp. 3&4	1-1/4	72	48				355	225	195	125	90	65	40	

^a These values apply for C-D Int, C-C Ext, Structural I and Structural II C-D Int, and Structural I and Structural II C-C Ext grades. Plywood continuous over 2 or more spans.

^b Provide adequate blocking, tongue and grooved edges, or other suitable edge support such as Plyclips when spans exceed indicated value. Use two Plyclips for 48" or greater spans and one for lesser spans.

^c Uniform load deflection limit: 1/180th span under live load plus dead load, 1/240th under live load only.

Table 132-10. Commercial roof decking—face grain parallel to supports.^a

5 psf dead load assumed.

Surface	Number & length of spans	Structural I Grades		Grades other than Structural I	
		Identification Index and thickness inch	Allowable uniform live load psf	Identification Index and thickness inch	Allowable uniform live loads psf (b)
Unsanded	Four @ 12"	24/0-3/8	35	24/0-1/2 (c) 24/0-1/2 (d)	50
	Three @ 16"	32/16-1/2 (d)	115	24/0-1/2 (d)	65
		32/16-1/2 (g)	75	32/16-1/2 (d)	70
	Two @ 24"	32/16-1/2 (g)	25	32/16-1/2 (d) (f)	25
		32/16-1/2 (d)	40	32/16-5/8 (d)	45
		42/20-5/8	80	42/20-5/8 (d)	45
		48/24-3/4	110	42/20-3/4	50
				48/24-3/4	50
				48/24-7/8	120
	One @ 48"	1 1/8	45	2-4-1	25
Sanded ^e	Four @ 12"	3/8	80	3/8 1/2	50 195
	Three @ 16"	3/8	30	1/2	80
		1/2	135	5/8	190
	Two @ 24"	1/2	45	5/8	65
		5/8	105	3/4	115
	One @ 48"	1 1/8	55	1 1/8	30

(a) All panel edges supported, as by Plyclips, tongue-and-groove edges or solid blocking.

(b) Deflection limitations: 1/180th for total load; 1/240th for live load only. Loads valid only for number of spans shown.

(c) Three-ply and 4-ply construction.

(d) Five-ply construction only.

(e) Sanded panel values other than Structural I are based on use of Group 1 panels. Reduce applicable loads by 5% for Group 2, 10% for Group 3 and 13% for Group 4 panels.

(f) Solid blocking recommended.

(g) Four-ply construction.

Floor Systems

Subflooring

A limiting factor in plywood floor design is deflection under concentrated loads, especially at panel edges. Table 132-11 gives minimum Identification Indexes recommended for the support spacings given. All the panels listed carry over 160 psf on their maximum span before deflecting 1/360 of the span.

The most common floor joist spacing for plywood subflooring is 16" o.c. Wider joist spacings such as 24", 32", and 48" o.c. also provide economical floor systems.

Underlayment

Underlayment plywood grades have a solid surface for direct application of nonstructural flooring, with special inner-ply construction to resist narrow-heel punch through and concentrated point loading. When thin vinyl flooring is used, give extra attention to face and edge smoothness. Where floors may be subjected to unusual moisture conditions, as in bathrooms and laundry areas, use panels with exterior glue.

Use 1/4" Underlayment Int or Ext, or C-C Plugged Ext over a well-laid plywood subfloor. Use similar 3/8" plywood over lumber subfloor or other uneven surface. But, 1/4" Group 1 Underlayment is

Table 132-11. Plywood subflooring.

Plywood continuous over two or more spans, face grain across supports.

These values apply for C-D Int, Structural I and II, C-D Int, C-C Ext, and Structural I and II C-C Ext grades only. Edges should be tongue and groove or supported with blocking for square-edge wood flooring, unless separate underlayment layer is installed, a minimum 1 1/2" of lightweight concrete applied over the plywood, or finish floor is 23/32" wood strip. Minimum thickness of this underlayment layer should be 1/4" for subfloors up to 48/24, and 3/8" for thicker panels on spans longer than 24".

Panel Identification Index	Plywood thickness inch	Maximum span inch
32/16	1/2, 5/8	16 ^a
42/20	5/8, 3/4, 7/8	20 ^b
48/24	3/4, 7/8	24
1-1/8" Groups 1 & 2	1-1/8	48
1-1/4" Groups 3 & 4	1-1/4	48

^a May be 24" if 25/32" wood strip flooring is installed at right angles to joists.

^b May be 24" if 25/32" wood strip flooring is installed at right angles to joists, or minimum 1-1/2" of lightweight concrete is applied over plywood.

adequate over floor boards up to 4" wide if the face grain is perpendicular to the boards.

Apply Underlayment just prior to laying finish floor or protect against water or physical damage. Stagger panel end joints with respect to each other and offset all joints with respect to the joints in the subfloor. Space panel ends and edges about 1/32". For maximum stiffness, place panel face grain across supports and end joints over framing. Unless subfloor and joists are thoroughly seasoned and dry, countersink nails 1/16" just prior to laying finish floor to avoid nail popping. Countersink staples 1/32". Fill any damaged, split, or open areas exceeding 1/16". Do not fill nail holes. Lightly sand any rough areas, particularly around joints and nail holes.

Combined subfloor-underlayment

Thin resilient floorings, carpeting, and other nonstructural finish floorings may be applied directly over plywood floors. Plywood panel edges must be tongue and groove or supported on 2" lumber blocking or joists. To minimize the effects of framing shrinkage use ring-shank nails. Set nails 1/16" or more just prior to finish floor installation. See Table 132-12 for recommended plywood grades and thicknesses.

Glued Floor System

The Glued Floor System is based on gluing techniques and mastic adhesives that firmly and permanently adhere structural plywood to wood joists. Floor and joists are fused into a T-beam unit that increases floor stiffness 10% to 90% when compared with conventional floor construction. Glue, rather than nails, carries the shear stress. Field-gluing also eliminates the squeaks which can result from shrinking lumber and nail popping.

Table 132-12. Combined subfloor-underlayment.

Face grain across supports.

Plywood edges should be tongue and groove, or supported with framing. Set nails 1/16" (1/8" for 2-4-1 panels). Don't fill nail holes.

Plywood grade	Plywood species group	Maximum support spacing		
		16" o.c.	20" o.c.	24" o.c.
		Panel thickness		
Underlayment Int	1	1/2"	5/8" ^b	3/4" ^a
Underlayment Ext	2&3	5/8" ^b	3/4" ^a	7/8"
(C-C Plugged Ext)	4	3/4" ^a	7/8"	1"
2-4-1	1,2&3	32" o.c. on 2" wide supports 48" o.c. on 4" wide supports		
(2-4-1 is 1 1/8" thick. Panels from all Groups have equal properties.)				

^a May be 23/32".

^b May be 19/32".

There are savings in material and labor by combining both subflooring and underlayment into a single-layer floor. Because the floor stiffness is added to that of the joists, they can span longer distances or smaller sizes can be used.

The essentials of the Glued Floor System are:

- Increase joist spacing or span, or reduce joist size, because of composite action of the floor system.
- Apply glue bead to framing and along panel groove edges with caulking gun. No bridging is required.
- Install one layer of T&G Underlayment grade plywood.
- Space nails 12" o.c. The glue effectively bridges any gaps or irregularities.
- Add finish flooring—tile, carpet, linoleum, etc.

Table 132-13 lists some plywood-lumber combinations for field-glued floors. The table is based on 1/360 of clear span deflection with a 40 psf live load. Composite action between plywood and lumber is used in calculating stiffness, but not strength. The joists can carry a 50 psf total load alone. The table is based on single layer floor construction, but may also be used for double layer floor construction.

Siding

Plywood siding is available in various species and dozens of textures. These range from the smooth Medium Density Overlay surface to the deep grooves and resawn texture of reverse board-and-batten patterns.

Plywood panel siding is strong enough that panels can be applied directly to studs, with the single layer performing both as structural sheathing and finished siding. Plywood siding resists blows that can dent or scar some other sidings. It also adds to the thermal insulation and acoustical values of a well designed wall section. Plywood provides a tight envelope around a building, helping to reduce wind and weather infiltration.

There are 4 basic categories of plywood siding: Medium Density Overlay, 303 Siding, Texture 1-11, and Qualified Coatings. All panels in these categories are Exterior type with waterproof glue. Most panels are 4' x 8', but siding is also available in 9' and 10' lengths; lap sidings to 16'.

Medium Density Overlay, MDO, has a special resin-treated surface that is an excellent smooth base for paint. MDO is available in both panel and lap siding.

Table 132-13. Allowable clear spans for glued floors, ft-in.

Species - grade	Joist size	5/8" plywood ^a joists 16" o.c.	3/4" plywood ^a joists 16" o.c.	3/4" plywood ^b joists 24" o.c.
Southern Pine or Douglas Fir-Larch No.1	2x6	11'-2"	11'-5"	9'-5"
	2x8	14-5	14-8	12-5
	2x10	18-2	18-4	15-10
	2x12	21-10	22-1	19-3
Douglas Fir-Larch No.2	2x6	10-6	10-6	8-7
	2x8	13-10	13-10	11-3
	2x10	17-7	17-7	14-5
	2x12	21-5	21-5	17-6
Douglas Fir South No.1	2x6	10-5	10-8	9-1
	2x8	13-6	13-9	12-0
	2x10	16-11	17-2	15-4
	2x12	20-4	20-7	18-5
Hem-Fir No.1 or Douglas Fir South No.2	2x6	10-1	10-1	8-3
	2x8	13-2	13-4	10-11
	2x10	16-7	16-10	13-10
	2x12	19-11	20-2	16-11
Southern Pine or Hem-Fir No.2	2x6	9-4	9-4	7-7
	2x8	12-4	12-4	10-0
	2x10	15-8	15-8	12-10
	2x12	19-1	19-1	15-7
Southern Pine KD 15% No.1	2x6	11-4	11-7	9-9
	2x8	14-8	14-10	12-11
	2x10	18-5	18-8	16-6
	2x12	22-2	22-5	20-0
Southern Pine KD 15% No.2	2x6	9-11	9-11	8-1
	2x8	13-1	13-1	10-8
	2x10	16-8	16-8	13-7
	2x12	20-3	20-3	16-7

^a Underlayment Int, Group 1, 2 or 3

^b Underlayment Int, Group 1

303 Sidings include a wide variety of surface textures and patterns; most of them were developed for optimum performance with stain finishes. Grade C veneer, with tight knots and knotholes repaired with synthetic filler, is permitted in some 303 Siding face plies. The grade stamp includes the stud spacing—16" or 24" o.c.

Texture 1-11 siding is a special panel manufactured in only $\frac{5}{8}$ " thickness with shiplapped edges and parallel surface grooves. It is available unsanded or with a variety of surface treatments.

Plywood with Qualified Coatings combines MDO or sanded plywood with metals, plastics, etc. Most applications have been in commercial buildings and apartments where low maintenance is paramount.

Plywood wall construction

Tables 132-14 and 132-15 apply to wall construction with 2 separate layers—siding over sheathing. Select plywood sheathing from Table 132-14 and siding from Table 132-15. The most common sheathing grade is C-D Int; Structural I or II may also be used. For installations in high moisture conditions, use Interior Plywood with Exterior glue or C-C Ext.

Plywood siding can also be applied directly over studs. Back all edges of panel siding with 2" framing or blocking. To prevent staining, use galvanized, aluminum, or other noncorrosive nails. No corner bracing is needed with single layer panel siding.

Building paper may be omitted if the joints are shiplapped or battened. Table 132-16 contains recommendations for single layer wall construction.

Preservative Treated Plywood

Pressure preserved plywood is impregnated with preservatives by a pressure process. The treatment increases resistance to decay, termites, carpenter ants and, with some treatments, marine borers.

Any grade, size, or thickness of exterior-glue plywood can be treated. Creosote and pentachlorophenol treatments are dark in color and have an "oiled" surface appearance. Water-borne salts leave a clean surface.

Creosote is not harmful to farm animals, but it is not recommended where odor may be a problem,

Table 132-14. Plywood wall sheathing.

Continuous over two or more spans.

Panel Identification Index	Panel thickness inch	Maximum stud spacing exterior covering nailed to:	
		Stud inch	Sheathing inch
12/0,16/0,20/0	5/16	16	16 ^a
16/0,20/0,24/0	3/8	24	16 24 ^a
24/0,30/12,32/16	1/2,5/8	24	24

^a Apply sheathing with face grain across studs.

Table 132-15. Exterior plywood siding over sheathing.^a

Recommendations apply to all species Groups.

Plywood siding		Thickness in.	Max. stud spacing in.	
			Face grain	
Type	Description		Vert	Horiz
Panel siding ^b	MDO Ext	5/16	16 ^d	24
	A-C Ext	3/8	16 ^d	24
	B-C Ext			
	C-C Plugged Ext	1/2 & thicker	24	24
	MDO Ext			
	T 1-11 Ext	5/8	16 ^d	24
	303-16 o.c. Siding Ext	5/16 & thicker	16 ^d	24
	303-24 o.c. Siding Ext	7/16 & thicker	24	24
Lap Siding ^c	MDO Ext	5/16	-	16 ^e
	A-C Ext	3/8	-	16 ^e
	B-C Ext			
	C-C Plugged Ext	1/2 & thicker	-	24
	MDO Ext			
	303-16 o.c. Siding Ext	5/16 or 3/8	-	16 ^e
	303-16 o.c. Siding Ext			
	303-24 o.c. Siding Ext	7/16 & thicker	-	24

^a Use nonstaining box, siding or casing nails, 6d for panels 1/2" thick or less and 8d for thicker panels.

^b Space nails 6" o.c. at panel edges and 12" o.c. at intermediate supports. Use next larger nail size when sheathing (other than plywood or lumber) is thicker than 1/2".

^c Space nails 4" o.c. at vertical butt joints and 8" o.c. at each intermediate stud if siding is wider than 12". Use one nail per stud along the bottom edge. Use next larger nail size when sheathing is other than plywood or lumber, and nail only into framing.

^d May be 24" with 1/2" plywood, or lumber sheathing, if panel is also nailed 12" o.c. between studs, provided panel joints fall over studs.

^e May be 24" with plywood or lumber sheathing.

Table 132-16. Single layer wall construction.^a

Recommendations apply to all species groups.

Use nonstaining box, siding, or casing nails, 6d for siding 1/2" thick or less and 8d for thicker siding.

Plywood siding			Max. stud spacing in.	
Type	Description	thickness inch	Face grain Vert	Horiz
Panel siding ^a	A-C Ext	3/8	16	24
	B-C Ext			
	C-C Plugged Ext	1/2 & thicker	24	24
	MDO Ext			
	T 1-11 Ext	5/8	16	24
	303-16 o.c. Siding Ext	5/16 & thicker	16	24
	303-24 o.c. Siding Ext	7/16 & thicker	24	24
Lap siding ^b	A-C Ext	3/8	-	16
	B-C Ext			
	C-C Plugged Ext	1/2 & thicker	-	24
	MDO Ext			
	303-16 o.c. Siding Ext	5/16 & thicker	-	16
	303-16 o.c. Siding Ext	7/16 & thicker	-	24
	303-24 o.c. Siding Ext			

^a Space nails 6" o.c. at panel edges and 12" o.c. at intermediate supports.^b Space nails 4" o.c. at vertical butt joints and 8" o.c. at each intermediate stud if siding is wider than 12". Use one nail per stud along the bottom edge.

or where painting is desired. Penta-treated plywood is non-corrosive, fairly clean to handle, and doesn't produce skin burn. A slight petroleum odor is apparent at first, but it diminishes. Ordinary penta can't be painted. Water-borne salts are recommended when clean, odorless, and paintable products are required.

Treated plywood normally can be cut in the field without loss of preservative protection at cut edges. Plywood can be glued after being treated with most of the salt preservatives.

Table 132-17. Recommended pressure preservative treatments.

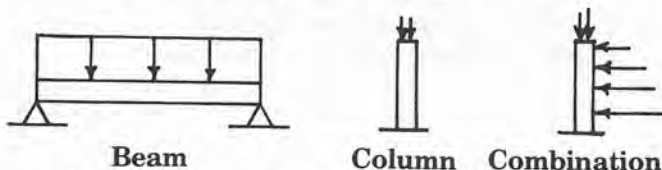
	Minimum preservative treatment lb/cu ft			
Exposure	Creosote	Penta	Salt preservatives	
Contact with sea water, exposed to marine borer attack.	25.0	Not	recommended	
Contact with ground, fresh water, chemicals, extreme humidities	10.0	0.50	ACA ACC CCA Type A, B or C	0.40 0.50 0.40
Above ground uses subject to sever insect infestation or fungus attack.	8.0	0.40	ACA ACC CCA Type A, B or C CZC FCAP	0.23 0.25 0.23 0.46 0.22

CHAPTER 133 WOOD GIRDERS AND COLUMNS

This chapter presents design tables developed for selecting structural elements for farm building plans. Design loads are discussed in Chapter 121, and design stresses in Chapter 131.

Definitions

A beam supports loads that try to bend it: joists, lintels, a diving board, ladder rungs, etc.



Beam

Column

Combination

A column supports loads that try to shorten it; studs or poles holding a roof, chair legs, ladder side rails, etc.

A support can be both; grain bin walls resist bending outward and also hold up the roof.

Rafters for low-slope roofs are commonly designed as beams, even though they carry some compression.

Lengths of Supports

Beams: Use span between supporting columns or walls.

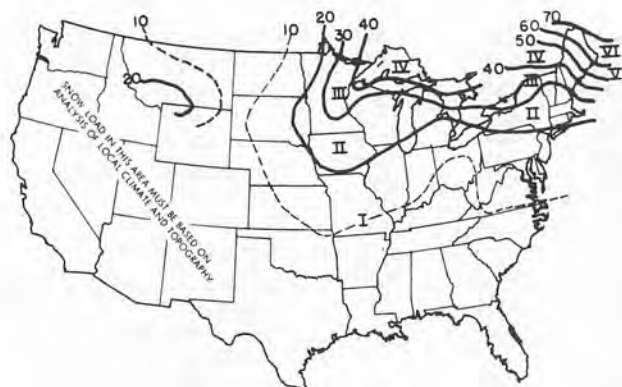
Joist = 15'

Lintel = 8'

Girder = 10'

Pole = 8'

Columns: Use total length



Zone I = 12 psf

Zone II = 18 psf

Zone III = 24 psf

Zone IV = 30 psf

Zone V = 36 psf

Zone VI = 42 psf

Fig 133-2. Snow zone map.

ANSI A58.1-1972

Design snow load, psf = Map load x 0.6

Map values should not be used for geographic areas subjected to unusual snow pack because of elevation or other special geographic features.

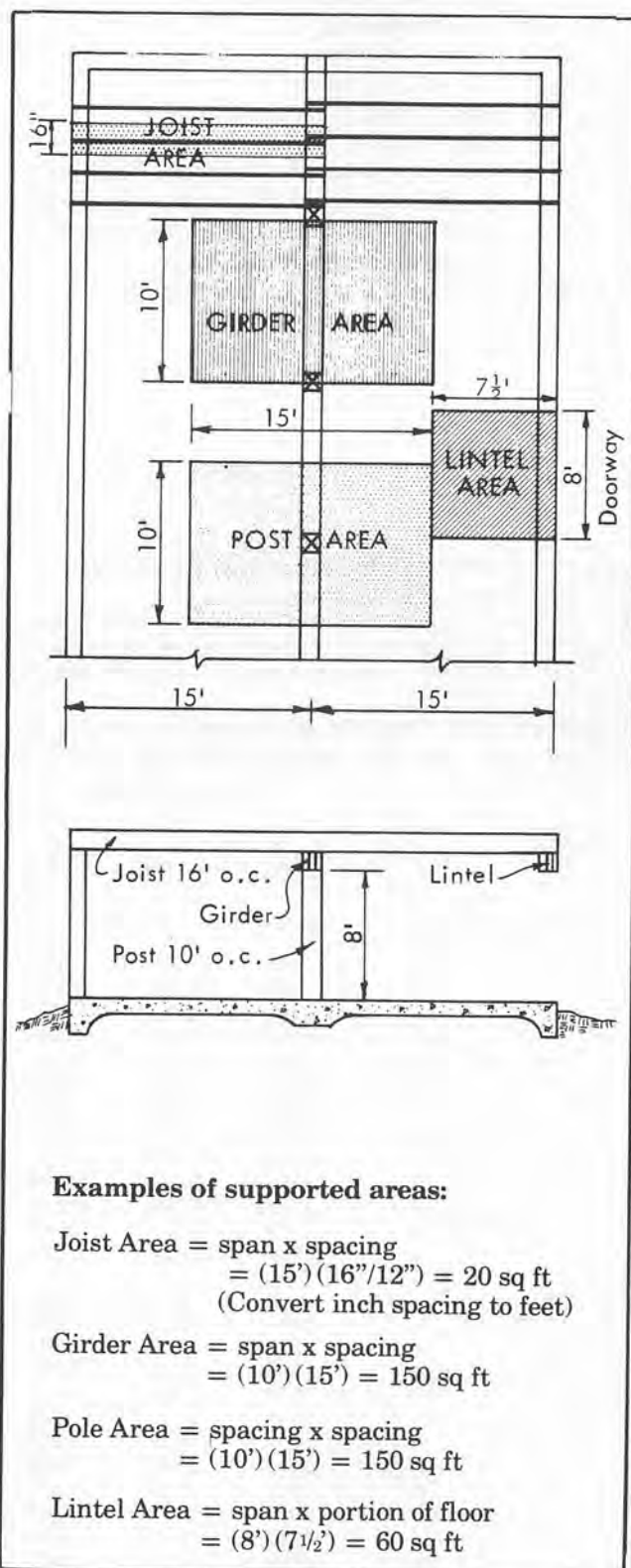


Fig 133-1. Loads on supports.

Girder Selection

Example

	Decide on the problem to be solved.
40'	Building span (width)
4'	Truss spacing
	Snow load zone
Zone 2	Central Iowa
8'	Pole spacing along walls
12'	Wall height
	Find the load (P) in pounds that each truss imposes on the girder. $P = \text{Load, psf (snow + dead, from Table 141-3)} \times \frac{1}{2} \text{ post spacing, ft} \times \text{span (ft)}$
4240 lb	$P = 26.5 \times \frac{1}{2}(8) \times 40 = 4240 \text{ lbs}$

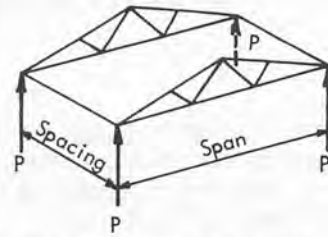


Table 133-1. With trusses 4' on center (o.c.) and poles 8' o.c., there will be one truss over each pole, and one midway between each pair of poles.

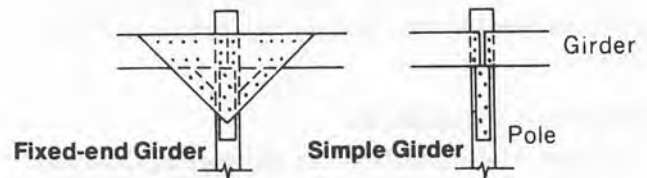
1-2x12	If girder is to be fixed-end
2-2x12	If girder is to be a simple beam

Table 133-1. Allowable loads on girders, P pounds.

Circled numbers refer to examples.

The tabulated load is P, not the total load on the girder, and is the maximum load in bending. Shear and deflection not checked. PS20-70 lumber sizes, stress = $1.15(1500) = 1725 \text{ psi}$.

Fixed-end girders are continuous across the poles or are attached with specially designed stiffened plywood gussets.



GIRDER SPAN	MEMBER SIZE*	FIXED END BEAM			SIMPLE BEAM		
		PPP 3	P P 2	P 1	PPP 3	P P 2	P 1
4'	6	869	1223	2173	543	815	1087
	8	1511	2125	3778	944	1417	1889
	66	1739	2445	4347	1087	1630	2173
	68	2380	3348	5951	1488	2232	2976
	10	2460	3459	6150	1537	2306	3075
	88	3022	4250	7555	1889	2833	3778
	12	3639	5117	9096	2274	3411	4548
	810	3971	5584	9927	2482	3723	4964
	1010	4920	6918	12299	3075	4612	6150
	1012	6098	8576	15246	3812	5717	7623
	1212	7277	10234	18193	4548	6822	9096
	101010	7380	10377	18449	4612	6918	9224
	121212	10916	15350	27289	6822	10234	13645
8'	6	435	611	1087	272	408	543
	8	756	1062	1889	472	708	944
	66	869	1223	2173	543	815	1087
	68	1190	1674	2976	744	1116	1488
	10	1230	1730	3075	769	1153	1537
	88	1511	2125	3778	944	1417	1889
	12	1819	2558	4548	1137	1706	2274
	810	1985	2792	4964	1241	1861	2482
	1010	2460	3459	6150	1537	2306	3075
	1012	3049	4288	7623	1906	2859	3812
	1212	3639	5117	9096	2274	3411	4548
	101010	3690	5189	9224	2306	3459	4612
	121212	5458	7675	13645	3411	5117	6822

If basic stress is, psi:
Multiply tabulated load by:

1000	0.67
1200	0.80
1400	0.93
1500	1.00
1600	1.07
1800	1.20

Loading cases:

In addition to a truss over each pole—

1. 1 truss at mid-span.
2. 2 trusses at $\frac{1}{2}$ points.
3. 3 trusses at $\frac{1}{4}$ points.

Note: For a given member size and the same load distribution (1, 2, 3), the allowable load for the fixed-end girder is 2, 1.5, and 1.6 respectively times the allowable load for a simple girder.

Table 133-1. continued.

GIRDER SPAN	MEMBER SIZE*	FIXED END BEAM			SIMPLE BEAM		
		PPP ↑ ↑ ↑ 3	P P ↑ ↓ 2	P ↑ 1	PPP ↑ ↑ ↑ 3	P P ↑ ↓ 2	P ↑ 1
12'	6	290	408	724	181	272	362
	8	504	708	1259	315	472	630
	66	580	815	1449	362	543	724
	68	793	1116	1984	496	744	992
	10	820	1153	2050	512	769	1025
	88	1007	1417	2518	630	944	1259
	12	1213	1706	3032	758	1137	1516
	810	1324	1861	3309	827	1241	1655
	1010	1640	2306	4100	1025	1537	2050
	1012	2033	2859	5082	1271	1906	2541
	1212	2426	3411	6064	1516	2274	3032
	101010	2460	3459	6150	1537	2306	3075
	121212	3639	5117	9096	2274	3411	4548
16'	6	217	306	543	136	204	272
	8	378	531	944	236	354	472
	66	435	611	1087	272	408	543
	68	595	837	1488	372	558	744
	10	615	865	1537	384	577	769
	88	756	1062	1889	472	708	944
	12	910	1279	2274	569	853	1137
	810	993	1396	2482	620	931	1241
	1010	1230	1730	3075	769	1153	1537
	1012	1525	2144	3812	953	1429	1906
	1212	1819	2558	4548	1137	1706	2274
	101010	1845	2594	4612	1153	1730	2306
	121212	2729	3838	6822	1706	2558	3411
Moment = $P \times L \times 12/J$; $J = 3.2$		4.5	8.0	2.0	3.0	4.0	

*6 = 2"x6", 66 = 2-2"x6", etc.

Design Features

Pole Analysis

Forces on poles are shown in Fig 133-3.

The maximum bending moment is at the top soil reaction at about $1/3$ of the embedment depth. The soil stress distribution, and an average allowable soil passive strength of 2500 psi, are from AWPI's Pole Building Design.

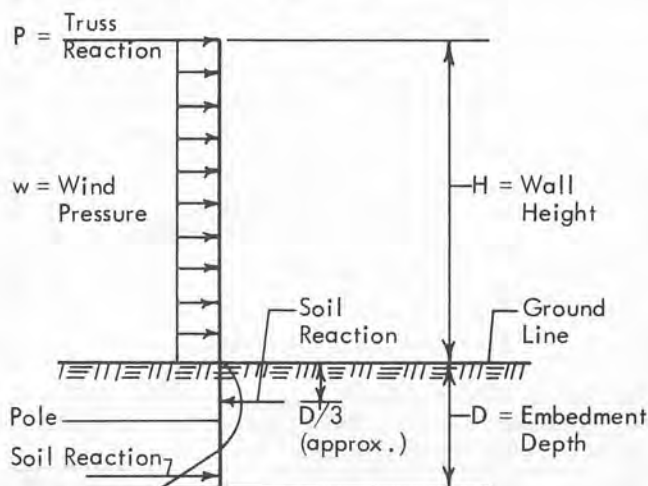


Fig 133-3. Pole load diagram.

The top of the pole can be designed as pinned or fixed. The maximum bending moments are (see symbols in Fig 133-3):

Top of the pole hinged:

$$M = P(H + D/3) + wH(H/2 + D/3)$$

Top of the pole fixed:

$$M = P(H + D/3)/2 + wH(H/2 + D/3)$$

$$= \frac{wH/6}{H + D/3} (H^2 + HD + D^2/3)$$

The interaction equation for moment and axial forces is evaluated to select an adequate member size:

$$\frac{M/S}{F_b} + \frac{P/A}{F_c \text{ or } F_t} \leq 1$$

Where: P = axial force; M = bending moment; A = area; S = section modulus; F_t = allowable tension stress; F_c = allowable compression stress; F_b = allowable bending stress. Usually, all units are in pounds and inches.

A pole's least dimension was used to check buckling stresses so the designs are valid for either a closed or open wall.

The required embedment depth was calculated from:

$$D = 1.47P + (2.16 + 10.52S_1BM)^{1/2}/2S_1B$$

Where: D = embedment depth, in.

P = horizontal truss reaction due to wind, lb.

S_1 = passive soil pressure; convert to lb/in², divide tabulated psf value by 144.

M = bending moment, in-lb.

B = width of the pole, in.

(Alternate compatible units are: D = ft, S_1 = psf, M = ft-lb, B = ft)

Pole-to-Truss Joint Fixity

To approximate a fixed joint at the top of a pole, fasten a knee brace at each pole, forming a triangle of at least 30" on a side. The knee brace is 2" dimension lumber as wide as the greatest width of the pole, e.g. a 2x6 for a 6x6 or a 2x8 for a 6x8. Securely anchor the knee brace to the pole and truss. Fig 133-4.

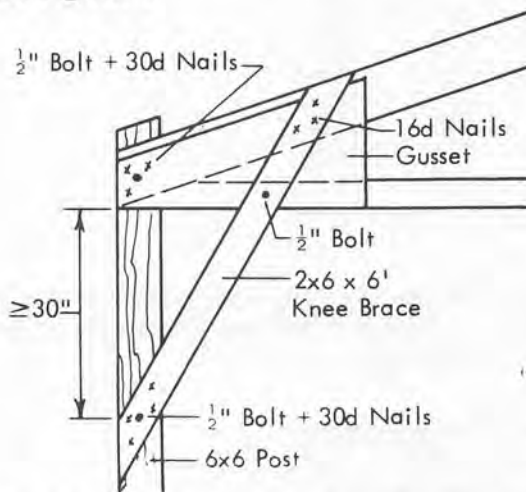


Fig 133-4. Typical fixed pole-to-truss connection. Use ringshank hardened nails and bolts with washers.

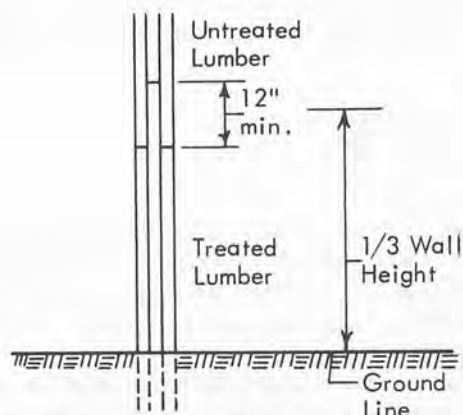


Fig 133-5. Laminated pole lap joint.

Splicing Dimension Lumber Poles

If dimension lumber poles are made with pressure preservative treated wood in the ground and untreated wood above ground, the pole-to-truss joint must be fixed, preferably by a knee brace. Join the treated and untreated lumber at approximately $1/3$ the wall height. Make the lap joint at least 12" long and securely nailed or bolted. See Fig 133-5.

Use of the Tables

Selection procedure:

1. Select type of pole desired.
2. Select pole spacing.
3. Select pinned or fixed pole-to-truss joint.
4. Determine building width and wall height.
5. Select required pole size.
6. Record the required embedment depth.

Pole selection tables assume each pole supports $1/2$ the lateral load on a building. When interior poles are used, each pole supports less load, as in the examples, Fig 133-6.

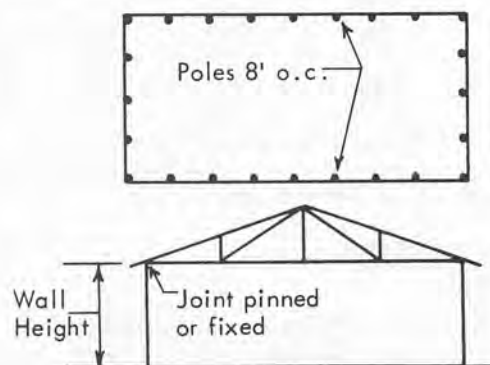


Fig 133-6a. Select sidewall poles for 8' o.c. Height = wall height.

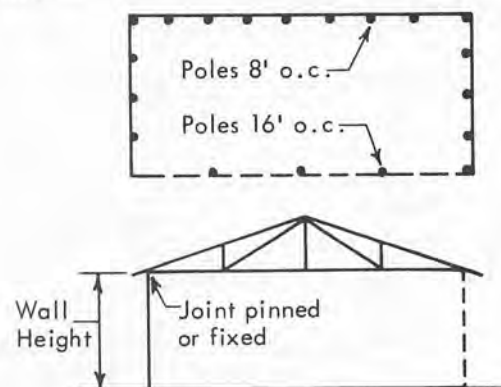


Fig 133-6b. Select sidewall poles for 12' o.c., $(16' + 8') / 2$, or closed wall poles for 8' o.c. and open front poles for 16' o.c. Height = wall height.

Fig 133-6. Examples of selecting proper pole spacing and height.

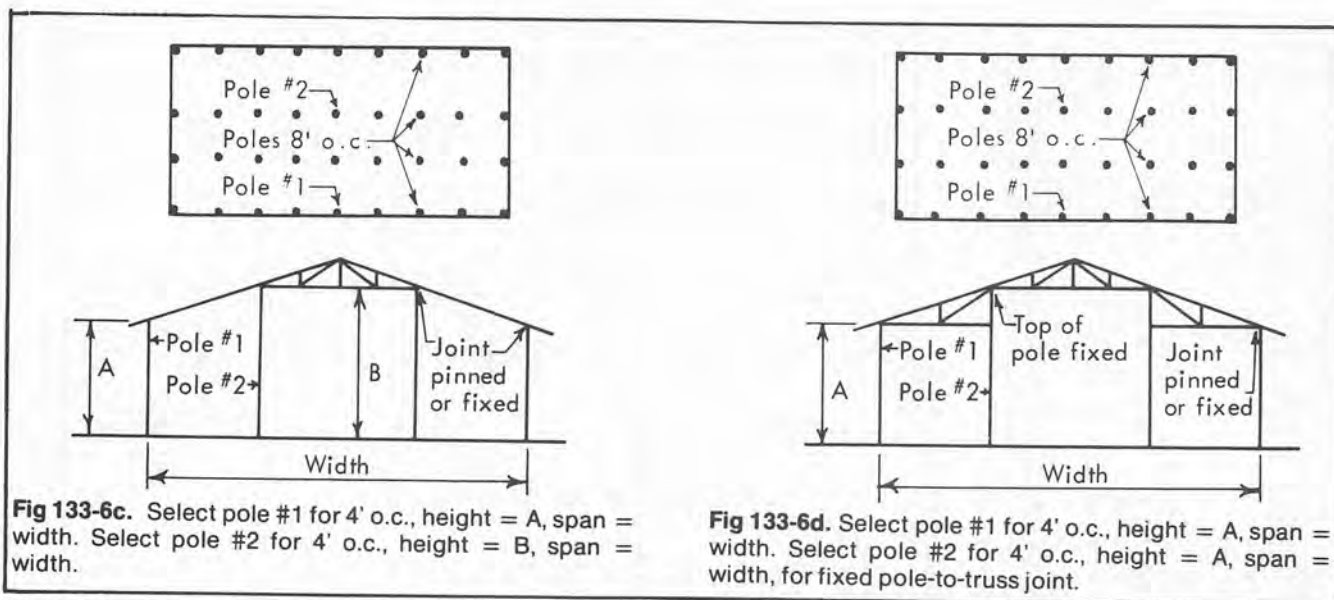


Fig 133-6. continued.

Table 133-2. Pole dimensions.

Sawn poles, in.		Round Poles, in. Assumed dia. taper of 0.075 in./ft		2" Dimension laminated poles, in. Repetitive member bending stresses used with 3-2x6's and up	
Nominal	Dressed	ASA Class	Top dia.	Nominal	Laminated
3x6	2½x5½	1	8.6	2-2x4	3x3½
4x4	3½x3½	2	8.0	2-2x6	3x5½
4x6	3½x5½	3	7.3	2-2x8	3x7¼
4x8	3½x7¼	4	6.7	3-2x6	4½x5½
4x10	3½x9¼	5	6.0	3-2x8	4½x7¼
5x5	4½x4½	6	5.4	3-2x10	4½x9¼
6x6	5½x5½	7	4.8	4-2x8	6x7¼
6x8	5½x7½	10	3.8	4-2x10	6x9¼
6x10	5½x9½			4-2x12	6x11¼
8x8	7½x7½			5-2x10	7½x9¼
8x10	7½x9½			5-2x12	7½x11¼
10x10	9½x9½			6-2x12	9x11¼

Main Wall Members

Example

Because fixed-end columns tend to bend in the slender direction, open wall poles may be larger than closed wall poles that are supported by girts and siding.

Round or sawn lumber poles with ends fixed (fixed-end columns) are preservative-treated members designed to be set in the ground for lateral support.

Sawn lumber poles (pin-end columns) extend from the girder to a foundation at or near the groundline.

Building span is 40', 12' wall and poles spaced at 8' o.c.

8x8

Table 133-4. Select poles for pinned top.
Depth of embedment.

48"

4x10

53"

Class 5

48"

6"

4x4 dressed
Doug fir

Table 133-4. Select poles for fixed top.

Depth of embedment.

Table 133-10. If poles are round.
Depth of embedment.

Table 133-2. Top diameter of Class 5 pole.

Table 133-11. Select foundation-supported poles (pin-end columns). Each pole supports a roof load: $8 \times \frac{1}{2}(20) = 160$ sq ft. Zone II, Table 141-3, 26.5 psf x 160 sq ft = 4240.

Douglas fir-larch or southern yellow pine poles.

Lumber grades	Allowable fiber stresses, psi		
	Bending F_b	Compression F_c	Tension F_t
Sawn poles (dressed and full size)			
Construction, 4x4	1050	1100	620
*No. 1, 3x6 & up	1200	825	800
Dimension lumber			
Const. grade @ 19%, 2x4	1050	1100	620
No. 1 @ 19%, 2x6 & up	1500	1250	1000
No. 1 @ 19%, 2x6 & up repetitive member	1750	1250	1000
Round poles	2125	1400	1150
(8000 psi ultimate strength; allowable stresses include 18% form factor)			
*For Southern yellow pine, 5x5 and up, bending stress can be 1300 psi; selection tables are in TR-6.			

Table 133-4. Sawn poles, dressed—8' o.c.

Pinned Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-24	Size Depth	6x6 48	4x8 48	4x10 52	4x10 57	4x10 61	8x8 48	8x8 49	6x10 62		
28-32	Size Depth	4x8 48	4x10 52	4x10 56	4x10 60	6x8 50	"	8x8 50	6x10 63		
36	Size Depth	4x8 49	4x10 54	4x10 58	4x10 62	6x8 54	8x8 49	6x10 61	8x10 54		
40-44	Size Depth	4x10 53	4x10 57	4x10 61	4x10 65	6x8 51	"	6x10 64	8x10 56		
48	Size Depth	4x10 54	4x10 59	4x10 63	4x10 67	6x8 54	8x8 49	6x10 62	8x10 57		
52-56	Size Depth	4x10 57	4x10 62	4x10 66	4x10 70	6x8 57	"	6x10 65	8x10 60		
60	Size Depth	4x10 59	4x10 64	4x10 68	4x10 72	6x8 59	8x8 61	6x10 67	8x10 62		
Fixed Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20	Size Depth	5x5 48	4x6 48	4x8 48	4x8 48	4x10 51	4x10 55	4x10 59	6x8 49		
24	Size Depth	4x6 48	"	"	"	"	"	"	"		
28-32	Size Depth	"	"	"	"	4x10 49	4x10 53	4x10 56	6x8 48		
36	Size Depth	6x6 48	"	"	4x8 48	4x10 51	4x10 54	4x10 57	8x8 48		
40-44	Size Depth	"	"	"	4x10 50	4x10 53	4x10 56	6x8 49	"		
48-52	Size Depth	"	"	4x8 49	4x10 52	4x10 55	4x10 58	6x8 48	"		
56-60	Size Depth	"	"	4x10 51	4x10 54	4x10 57	6x8 49	"	"		

Table 133-3. Sawn poles, dressed—4' o.c.

Pinned Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-24	Size Depth	5x5 48	4x6 48	4x6 48	6x6 48	6x6 48	4x8 48	4x10 51	4x10 54		
28-32	Size Depth	"	4x6 48	"	"	"	4x10 49	4x10 52	4x10 55		
36	Size Depth	"	"	"	"	4x8 48	4x10 50	4x10 53	4x10 56		
40	Size Depth	4x6 48	6x6 48	"	"	4x10 49	4x10 52	4x10 55	4x10 57		
44-48	Size Depth	"	"	"	4x10 48	4x10 51	4x10 54	4x10 57	6x8 48		
52	Size Depth	6x6 48	"	"	4x10 49	4x10 52	4x10 55	4x10 58	"		
56-60	Size Depth	"	"	"	4x8 48	4x10 51	4x10 54	4x10 57	6x8 49		
Fixed Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-28	Size Depth	3x6 48	3x6 48	5x5 48	5x5 48	4x6 48	4x6 48	6x6 48	6x6 48		
32	Size Depth	"	"	5x5 48	"	6x6 48	"	"	"		
36-40	Size Depth	"	"	"	"	4x6 48	"	"	"		
44	Size Depth	"	"	"	6x6 48	"	"	"	"		
48-52	Size Depth	"	5x5 48	"	4x6 48	"	"	"	4x10 48		
56-60	Size Depth	"	"	4x6 48	6x6 48	"	"	"	"		

List of Tables

- Table 133-3. Sawn poles, dressed—4' o.c.
 Table 133-4. Sawn poles, dressed—8' o.c.
 Table 133-5. Sawn poles, full size—4' o.c.
 Table 133-6. Sawn poles, full size—8' o.c.
 Table 133-7. 2" dimension laminated poles—4' o.c.
 Table 133-8. 2" dimension laminated poles—8' o.c.
 Table 133-9. Round poles—4' o.c.
 Table 133-10. Round poles—8' o.c.

Enter table with:

Pinned Top or Fixed Top.

Building span.

Wall height.

Read:

Required pole size.

Required depth of set.

Circled numbers refer to examples.

Table 133-7. continued.

Fixed Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-32	2-2x6 48	2-2x6 48	2-2x6 48	2-2x6 48	2-2x6 48	2-2x6 48	2-2x8 48	2-2x8 48	2-2x8 48		
36-44	"	"	"	"	"	2-2x8 48	"	"	2-2x8 49		
48-56	"	"	"	"	2-2x8 48	"	"	2-2x8 49	3-2x6 48		
60	"	"	"	2-2x8 48	"	"	"	3-2x6 48	"		

Table 133-8. continued.

Fixed Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-24	Size Depth	2-2x6 48	2-2x8 48	2-2x8 48	2-2x8 51	3-2x8 48	3-2x8 48	3-2x8 52	3-2x8 55		
28-36	Size Depth	"	2-2x8 48	"	2-2x8 52	3-2x6 48	3-2x8 50	3-2x8 53	"		
40	Size Depth	2-2x8 48	"	2-2x8 49	3-2x6 48	3-2x8 48	3-2x8 51	3-2x8 54	3-2x8 57		
44-52	Size Depth	"	2-2x8 50	"	"	"	3-2x8 51	3-2x8 54	3-2x8 57		
56-60	Size Depth	2-2x8 49	2-2x8 52	3-2x6 48	3-2x8 48	3-2x8 50	3-2x8 53	3-2x6 48	4-2x8 53		

Table 133-9. Round poles—4'o.c.

Pinned Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-28	Class Depth	-10- 48	-10- 48	-7- 48	-7- 48	-7- 48	-7- 48	-7- 48	-7- 48		
32-36	Class Depth	"	-7- 48	"	"	"	"	"	"		
40-44	Class Depth	"	-7- 48	"	"	"	"	"	-6- 48		
48-52	Class Depth	"	"	"	"	"	"	-6- 48	"		
56	Class Depth	"	"	"	"	"	-6- 48	"	"		
60	Class Depth	"	"	"	"	-6- 48	"	"	"		

Fixed Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-40	Class Depth	-10- 48	-10- 48	-10- 48	-10- 48	-10- 48	-10- 48	-10- 48	-7- 48		
44-48	Class Depth	"	"	"	"	"	"	-7- 48	"		
52-60	Class Depth	"	"	"	"	"	-7- 48	"	"		

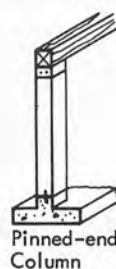
Table 133-10. Round poles—8'o.c.

Pinned Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-28	Class Depth	-7- 48	-7- 48	-6- 48	-6- 48	-5- 48	-5- 48	-5- 50	-4- 50		
32	Class Depth	"	-6- 48	"	"	-5- 48	"	-5- 51	-4- 51		
36	Class Depth	"	"	"	"	"	"	-5- 49	-4- 50		
40-44	Class Depth	-6- 48	"	"	-5- 48	-5- 49	-4- 49	-4- 52	-4- 54		
48	Class Depth	"	"	-5- 48	"	-5- 50	-4- 50	-4- 53	-4- 55		
52-56	Class Depth	"	-5- 48	"	"	-5- 50	-4- 53	-4- 55	-3- 55		
60	Class Depth	"	"	"	"	-4- 49	-4- 51	-3- 54	-3- 56		

Fixed Top - Exp. B		Wall Height									
Span	8	9	10	11	12	13	14	15	16		
20-32	Class Depth	-10- 48	-7- 48	-7- 48	-7- 48	-7- 48	-6- 48	-6- 48	-6- 48		
36	Class Depth	-7- 48	"	"	"	"	"	"	"		
40-48	Class Depth	"	"	"	"	"	-6- 48	"	"		
52-60	Class Depth	"	"	"	"	-6- 48	"	"	-5- 48		

Table 133-11. Allowable load supported by pinned-end columns, lb. Load = (snow load + dead load, psf) x ½ span x pole spacing. Circled numbers refer to examples. Tabulated values are based on the following assumptions:

Pole designs in Table 133-11 are for compression only, and do not allow for lateral wind stability. If either one or both ends of the column is fixed, select the column size as if it were embedded, Tables 133-3 to 10.



		Allowable fiber stress psi	Modulus of elasticity psi
Doug fir - larch		1250	1,800,000
Hem - fir		1000	1,500,000

Pole dimension	Height ft	Load, lb	
		Doug fir	Hem fir
4x4 dressed	8'	9665	8084
	10'	6162	5133
	12'	4288	3577
	14'	3148	2622
4x4	8'	15,584	12,768
	10'	10,528	8,768
	12'	7,312	6,096
	14'	5,376	4,480
	16'	4,112	3,424
5x5 dressed	8'	21,850	17,719
	10'	16,808	13,973
	12'	11,705	9,761
	14'	8,627	7,189
	16'	6,581	5,488
5x5	18'	5,204	4,334
	8'	28,425	22,925
	10'	24,350	19,950
	12'	17,850	14,875
	14'	13,125	10,925
	16'	10,050	8,375
6x6 dressed	18'	7,925	6,600
	20'	6,425	5,350
	8'	35,453	28,496
	10'	32,125	26,076
	12'	24,955	21,568
	14'	19,269	16,063
6x6	16'	14,732	12,251
	18'	11,586	9,680
	20'	9,438	7,865
	8'	43,020	34,560
	10'	40,212	32,508
	12'	35,064	28,278
	14'	27,180	22,644
	16'	20,808	17,352
	18'	16,452	13,716
	20'	13,320	11,088

CHAPTER 134 FASTENERS

Much of this chapter is an abstract from the NDS and applies primarily to the more common structural woods. Refer to NDS for details for other species.

Table 134-1. Specific gravity, G , of selected wood species. Based on oven-dry weight and volume.

Group	Typical Species	Specific Gravity
I	Birch, Maple	0.66
	Ash	0.62
II	Douglas Fir-Larch	0.51
	Southern Pine	0.55
III	California Redwood; Idaho White, Ponderosa, Sugar, and Red Pines	0.42
	Douglas Fir, south; Southern Cypress	0.48
IV	Balsom Fir, E. White Pine	0.38

Nails and Spikes

Allowable loads are per nail, and may be adjusted for duration of loading. Loads for nails and spikes may be increased 30% in diaphragm construction. For lumber pressure-treated with fire retardants, reduce nail and spike loads to:

- 90% in withdrawal if kiln dried after treatment
- 22-1/2% in withdrawal if not kiln dried after treatment
- 66-3/4% in lateral resistance.

Table 134-2. Nail sizes. "Steel nails" are threaded, hardened steel.

Penny-weight	Length inches	Wire diameter, Inches		Spikes
		Wire nails	Steel nails	
4d	1-1/2"	0.098"	---	
6d	2	0.113	0.120"	
8d	2-1/2	.131	.120	
10d	3	.148	.135	0.192"
12d	3-1/4	.148	.135	.192
16d	3-1/2	.162	.148	.207
20d	4"	.192"	.177"	.225"
30d	4-1/2	.207	.177	.244
40d	5	.225	.177	.263
50d	5-1/2	.244	.177	.283
60d	6	.262	.177	.283
70d	7"		.207"	
80d	8		.207	
90d	9		.207	
5/16	7			.312
3/8	8-1/2			.375

Withdrawal

Withdrawal from end grain is prohibited; avoid joints requiring strength in withdrawal from side grain. Reduce tabulated load for nails and spikes to 25% if driven into green wood that will season

in use. Use 2/3 of the withdrawal load for withdrawal of toe-nails. See Table 134-3.

Lateral resistance

Strength in end grain for nails and spikes is 2/3 of the tabulated load.

In double shear, with nail fully penetrating all three members:

- Increase 1/3, each side member not less than 1/3 the thickness of the middle member.
- Increase 2/3, each side member equal to middle member.
- Double for wire nails to 12d with at least 3 diameters clinched over side members at least 3/8" thick. Similarly for hardened steel nails, but not clinched.
- Increase 1/4 for wire nails or spikes with properly designed metal side plates.
- Decrease to 3/4 for wire nails or spikes in unseasoned wood used wet or loaded before seasoning; and for wood pressure-impregnated with fire-retardant chemicals.

Bolts

Tabulated loads are for:

- normal load duration
- one common bolt in double shear in 3-member joint
- any grade of the wood species tabulated
- wood seasoned to its moisture content in service
- bolt holes 1/32" to 1/16" larger than the bolt
- loose nuts because of lumber shrinkage
- washer, plate, or strap under head and nut
- side plates 1/2 or more as thick as main member
- bolt length in main member

Adjustments

Green lumber. Full load may be used, even if lumber dries in service for wood side members with: a single bolt loaded parallel or perpendicular; single row of bolts loaded parallel; rows of bolts loaded parallel with separate splice plate for each row; or with metal gussets and a single row parallel to the grain in each member and loaded parallel or perpendicular. For other patterns, use 40% of tabulated load.

Reduce to 75% if exposed to weather, 67% if always wet.

With metal side plates, increase to 125% for parallel-to-grain loads.

For side members less than 1/2 thickness of main member, use tabulated load for main member twice as thick as thinnest side member.

Reduce load to 1/2 for single shear, two members of equal thickness.

For single shear, unequal side members, use 1/2 of load for member twice as thick as the thinner member.

For joints with more than 3 members of equal thickness, allow 1/2 tabulated load for each shear plane.

Table 134-3. Allowable loads on nails and spikes.

Normal load duration loads for 6d-20d threaded, hardened steel nails are the same as for common wire nails.

Withdrawal loads, lb/
inch of penetration in
side grain of seasoned
wood or unseasoned
that will remain wet.
Normal duration.

Specific gravity G	Common Nail												Threaded Nail							
	d =																			
	4	6	8	10	12	16	20	30	40	50	60	30	40	50	60	70	80	90		
.66	47	55	64	72	72	79	94	101	110	119	128	94	94	94	94	110	110	110		
.62	42	47	55	62	62	68	80	86	94	102	110	80	80	80	80	94	94	94		
.55	30	34	39	44	44	49	57	61	67	73	79	57	57	57	57	67	67	67		
.51	27	29	34	38	38	42	49	53	58	63	68	49	49	49	49	58	58	58		
.48	21	25	29	33	33	36	42	46	50	54	58	42	42	42	42	50	50	50		
.42	15	18	21	23	23	25	30	33	35	38	41	30	30	30	30	35	35	35		
.38	12	14	16	18	18	20	24	25	28	30	32	24	24	24	24	28	28	28		
	Common Spike																			
	d =																			
	10	12	16	20	30	40	50	60	5/16"	3/8"										
.66	94	94	101	110	119	128	138	138	152	183										
.62	80	80	86	94	102	110	118	118	130	156										
.55	57	57	61	67	73	79	84	84	93	111										
.51	49	49	53	58	63	68	73	73	80	96										
.48	42	42	46	50	54	58	62	62	69	83										
.42	30	30	33	35	38	41	45	45	49	59										
.38	24	24	25	28	30	32	35	35	38	46										

Lateral loads (shear) lb per nail.
Penetration into member holding
the point at least equal to
requirements of Table 134-4.

	Common Nail												Threaded Nail	
	d =												30-60	70-90
	4	6	8	10	12	16	20	30	40	50	60			
Group I	52	78	97	116	116	132	171	191	218	249	276		171	218
Group II	38	63	78	94	94	107	139	154	176	202	223		139	176
Group III	28	51	64	77	77	88	113	126	144	165	182		113	144
Group IV	28	41	51	62	62	70	91	101	116	132	146		91	116
	Common Spike													
	d =												5/16"	3/8"
	10,12	16	20	30	40	50,60	5/16"	3/8"						
Group I	171	191	218	249	276	306	357	469						
Group II	139	155	176	202	223	248	289	380						
Group III	113	126	144	165	182	202	236	310						
Group IV	91	101	116	132	146	162	189	248						

Table 134-4. Penetration (inches) of nails to develop lateral resistance.

Data rounded up. Group I = 10 diameters, II = 11, III = 13, IV = 14. Minimum penetration = 1/3 tabulated. Reduce load by linear interpolation.

Common Nails																			
	6	8	10-12	16	20	30	40	50	60										
I	1.2	1.4	1.5	1.7	2.0	2.1	2.3	2.5	2.7										
II	1.3	1.5	1.7	1.8	2.2	2.3	2.5	2.7	2.9										
III	1.5	1.7	2.0	2.2	2.5	2.7	3.0	3.2	3.5										
IV	1.6	1.9	2.1	2.3	2.7	2.9	3.2	3.5	3.7										
Threaded Nails										Spikes									
	6-8	10-12	16	20-60	70-90						10-12	16	20	30	40	50-60	5/16"	3/8"	
I	1.2	1.4	1.5	1.8	2.1						I	2.0	2.1	2.3	2.5	2.7	2.9	3.2	3.8
II	1.4	1.5	1.7	2.0	2.3						II	2.2	2.3	2.5	2.7	3.0	3.2	3.5	4.2
III	1.6	1.8	2.0	2.3	2.7						III	2.5	2.7	3.0	3.2	3.5	3.7	4.1	4.9
IV	1.7	1.9	2.1	2.5	3.0						IV	2.7	2.9	3.2	3.5	3.7	4.0	4.4	5.3

Placement

Member strength is computed for the net section, after bolt holes are drilled.

Bolts spacings are computed from their centerlines.

Parallel to grain loading, min. spacing = 4 diam.

Perpendicular to grain loading: if design load is less than bolt bearing capacity of side members, reduce spacing proportionally from 4 diam. min.

Rows of bolts, parallel loading, space rows at least 1-1/2 diameters.

Rows of bolts, perpendicular loading, space rows at least 2-1/2 diam with $L/d = 2$; 5 diam with $L/d = 6$ or more; straight line interpolation for L/d between 2 and 6.

No more than 5" between rows of bolts paralleling the member, or use separate splice plates.

End distance, parallel loading: in tension, 7 diam in softwoods, 5 diam in hardwoods; in compression, 4 diam.

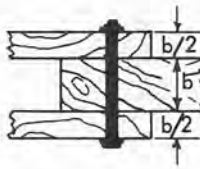
End distance, perpendicular loading: 4 diam.

Edge distance, parallel loading: 1-1/2 diam, except if L/d is greater than 6, use 1/2 row spacing.

Edge distance, perpendicular loading: 4 diam to loaded edge, 1-1/2 diam to unloaded edge.

Staggered bolts, parallel loading: adjacent bolts computed as if at critical section unless spaced at least 8 diam. Perpendicular loading: if design load of main member is less than bolt bearing capacity of side member, staggering may be employed.

Table 134-5. Loads in pounds on one bolt in double shear*.

				1		2		3		4		5	
				DOUGLAS FIR-LARCH (Dense) SOUTHERN PINE (Dense)		ASH, Commercial White, HICKORY		CALIFORNIA REDWOOD (Close grain), DOUGLAS FIR-LARCH SOUTHERN PINE (Med. grain), SOUTHERN CYPRESS		BEECH, BIRCH, Sweet & Yellow, MAPLE, Black & Sugar		OAK, Red & White	
Length of bolt in main member, l	Diameter of bolt, D	l/d	Projected area of bolt A = lxd sq. in.	Parallel to grain P lb	Perpendicular to grain Q lb	Parallel to grain P lb	Perpendicular to grain Q lb	Parallel to grain P lb	Perpendicular to grain Q lb	Parallel to grain P lb	Perpendicular to grain Q lb	Parallel to grain P lb	Perpendicular to grain Q lb
1 1/2	1/2	3.00	.750	1,120	500	1,080	780	960	430	900	480	830	650
	5/8	2.40	.937	1,410	570	1,360	880	1,210	490	1,130	540	1,050	730
	3/4	2.00	1.125	1,700	630	1,630	980	1,460	540	1,360	600	1,260	820
	7/8	1.71	1.312	1,990	660	1,910	1,070	1,700	590	1,590	660	1,470	900
	1	1.50	1.500	2,270	760	2,180	1,170	1,940	650	1,820	730	1,680	980
2 1/2	1/2	5.00	1.250	1,510	840	1,450	1,290	1,290	720	1,210	800	1,130	1,080
	5/8	4.00	1.562	2,190	950	2,100	1,460	1,870	810	1,750	900	1,620	1,220
	3/4	3.33	1.875	2,780	1,050	2,664	1,630	2,370	900	2,220	1,010	2,060	1,360
	7/8	2.86	2.187	3,290	1,160	3,150	1,790	2,810	990	2,630	1,110	2,440	1,500
	1	2.50	2.500	3,770	1,270	3,620	1,960	3,220	1,080	3,020	1,210	2,800	1,640
3 1/2	1/2	7.00	1.750	1,530	1,020	1,460	1,570	1,300	970	1,220	1,090	1,130	1,130
	5/8	5.60	2.187	2,400	1,300	2,300	2,010	2,050	1,130	1,920	1,270	1,780	1,680
	3/4	4.67	2.625	3,350	1,480	3,210	2,280	2,860	1,260	2,680	1,410	2,480	1,910
	7/8	4.00	3.062	4,290	1,620	4,110	2,510	3,670	1,390	3,430	1,550	3,180	2,100
	1	3.50	3.500	5,140	1,770	4,930	2,740	4,390	1,520	4,110	1,690	3,810	2,290
5 1/2	5/8	8.80	3.437	2,400	1,390	2,300	2,140	2,050	1,400	1,920	1,570	1,780	1,780
	3/4	7.33	4.125	3,440	1,920	3,300	2,970	2,940	1,880	2,750	2,110	2,550	2,480
	7/8	6.29	4.812	4,670	2,410	4,480	3,710	3,990	2,170	3,730	2,430	3,460	3,100
	1	5.50	5.500	6,140	2,750	5,900	4,240	5,250	2,380	4,920	2,660	4,560	3,550
	1 1/4	4.40	6.875	9,080	3,260	8,720	5,040	7,770	2,790	7,270	3,120	6,740	4,210
7 1/2	5/8	12.00	4.687	2,400	1,210	2,300	1,860	2,050	1,260	1,920	1,410	1,780	1,560
	3/4	10.00	5.625	3,440	1,760	3,300	2,710	2,940	1,810	2,750	2,030	2,550	2,270
	7/8	8.57	6.562	4,670	2,390	4,480	3,690	3,990	2,420	3,730	2,700	3,460	3,090
	1	7.50	7.500	6,140	3,060	5,900	4,730	5,250	3,040	4,920	3,400	4,560	3,950
	1 1/4	6.00	9.375	9,540	4,280	9,150	6,610	8,150	3,800	7,630	4,250	7,080	5,530

*3-member joint

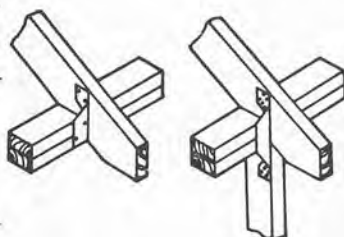
TIMBER FASTENERS

Many special hardware items from several manufacturers aid in developing structural strength in timber joints. The illustrations below show some typical shapes and uses. Design loads given are examples only; use allowable loads, and application and installation information, furnished by the manufacturer. In some cases special nails are required. Split ring connectors require detailed design, as allowable loads vary considerably with edge and end spacing, slope of grain, ring spacing, and number of lumber faces affected.

Rafter Anchors

Recommended Safe Working Values

Species Group	Resistance to Wind Uplift, pounds
I	965 lb
II	780
III	550
IV	410

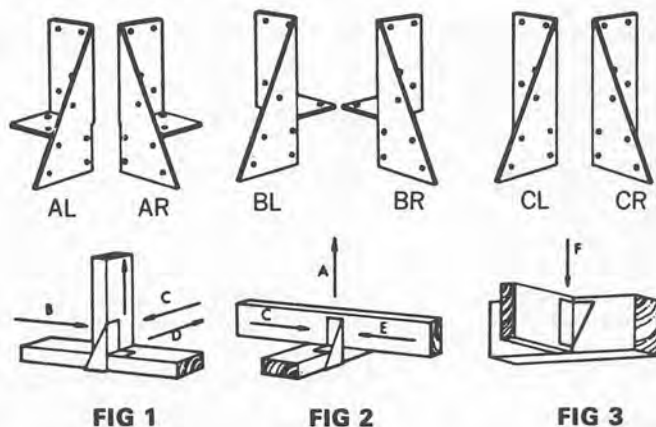


Framing Anchors

Recommended Safe Working Values, Pounds

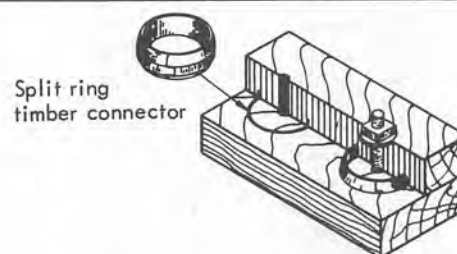
Direction of Load	A	B	C	D	E	F
Short Term Loading (Wind or Earthquake)	450	825	420	300	450	675
Long Term Loading (Live & Dead Loads)	300	530	290	200	300	450

Values given are for one anchor in pounds.



Split Rings

Inside Dia.	Depth	Bolt Dia.	Lumber, Minimum Dimensions Ring in One Face	Rings in Both Faces
2 1/2"	3/4"	1/2"	1" x 3 5/8"	1 5/8" x 3 5/8"
4"	1"	3/4"	1" x 5 1/2"	1 5/8" x 5 1/2"



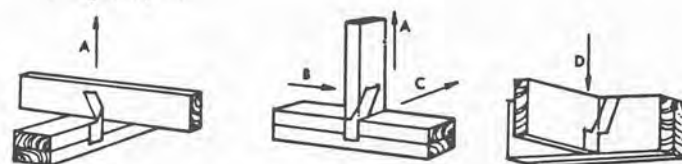
Framing Anchors

Recommended Safe Working Values

Values shown are for one anchor in pounds

Direction of Load	Long Term Loading* (Live and Dead Loads)
A	400
B	300
C	120
D	400

*The above values for permanent load may be increased from 33 1/3% to 50% for short duration loading such as wind and earthquake, depending upon local building code practice.



Joist Supports

Recommended Joist or Beam Size	Steel Ga.	Height	Seat Width	Recommended Seat Depth	Recommended Safe Working Values
2x4	18	3 1/4"	1 5/8"	2"	400 lb
2x6-8	18	5 1/4"	1 5/8"	2	900
2x8-10-12	18	7	1 5/8"	2	1000
2x10-12-14	18	8 1/2"	1 5/8"	2 3/4	1200
(2) 2x6-8	16	5 1/4"	3 1/4"	2 3/4	1700
(2) 2x8-10-12	16	7	3 1/4"	2 3/4	2200
(2) 2x10-12-14	16	8 1/2"	3 1/4"	2 3/4	2800
3x6-8	16	5 1/4"	2 5/8"	2 3/4	1700
2x10-12-14	16	8 1/2"	2 5/8"	2 3/4	2800
4x6-8	16	5 1/4"	3 5/8"	2 3/4	1700
4x10-12-14	16	8 1/2"	3 5/8"	2 3/4	2800

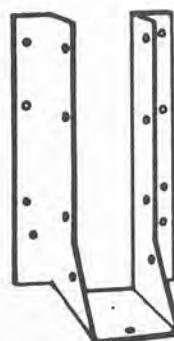


Table 134-6. Wire nails—kinds and quantities required.

American Steel & Wire Company Manual of Carpentry

Trade Names	Approx. no. to lb. Nailings		Sizes & kinds of material	Pounds per 1000 ft B.M. on center as follows:				
				12"	16"	20"	36"	48"
8d common	106	2	1x 4	60	48	37	23	20
8d common	106	2	1x 6	40	32	25	16	13
8d common	106	2	1x 8	31	27	20	12	10
8d common	106	2	1x10	25	20	16	10	8
8d common	106	3	1x12	31	24	20	12	10
20d common	31	2	2x 4	105	80	65	60	33
20d common	31	2	2x 6	70	54	43	27	22
20d common	31	2	2x 8	53	40	53	21	17
20d common	31	3	2x10	60	50	40	25	10
20d common	31	3	2x12	52	41	33	21	17
60d common	11	2	3x 4	197	150	122	76	61
60d common	11	2	3x 6	131	97	82	52	42
60d common	11	2	3x 8	100	76	61	38	34
60d common	11	3	3x10	178	137	110	70	55
60d common	11	3	3x12	145	115	92	58	46
8d finish	189	2	Base, per 100 ft lin		1			
8d common	106	2	Byrket lath		48			
8d finish	189	1	Ceiling, 3/4x4	18	14			
6d finish	309	1	Ceiling 1/2 and 5/8	11	8			
8d finish	189	2	Finish, 7/8	25	12			
10d finish	121	2	Finish, 1-1/8	12	10			
8d floor brads	99	1	Flooring, 1x3	42	32			
8d floor brads	99	1	Flooring, 1x4	32	26			
8d floor brads	99	1	Flooring, 1x6	22	18			
20d common	31		Framing, 2x4, to 2x16	20	16	14		
16d common	49		requires 3 or more sizes	10	10	8		
10d common	69		and vary greatly.	8	6	5		
60d common	11		Framing, 3x4 to 3x14	30	25	20		
8d casing	145	2	Siding, drop, 1x4	45	35			
8d casing	145	2	Siding, drop, 1x6	30	25			
8d casing	145	2	Siding, drop, 1x8	23	18			
6d finish	309	1	Siding, bevel, 1/2x4	23	18			
6d finish	309	1	Siding, bevel, 1/2x6	15	13			
6d finish	309	1	Siding, bevel, 1/2x8	12	10			
6d and 8d casing			Casing, per opening	About 1/2 pound per side				
3d brads	568	12"	Flooring, 3/8x2	About 10 pounds per 1000				
		o.c.		sq ft				
3d fine	778	16"	Lath, 48"	6 pounds per 1000 pieces				
		o.c.						
3d shingle	429	-	Shingles*	4 1/2 pounds; about 2 nails				
				each 4 in.				
4d shingle	274	-	Shingles	7 1/2 pounds; about 2 nails				
				to each 4 in.				

* Wood shingles vary in width. Regardless of width 1000 shingles are the equivalent of 1000 pieces 4 in. wide.

CHAPTER 135

REINFORCED CONCRETE MANURE TANK SELECTION TABLES

Walls, lids, slats, beams, columns, footings

This chapter is intended primarily for engineers with an understanding of reinforced concrete design. While it includes design criteria and adequate reinforcing for selected sections, many essential details are not included, such as wall foundations, corner reinforcing, design of necessary openings in walls or lids, etc.

A plan based on this information is available from the MWPS at a nominal price; order Plan 74303, Liquid Manure Tanks.

Table Summary

Reinforced with Deformed Bars

- Table 135-1. Allowable stresses, ultimate design.
- Table 135-2. Reinforcing steel.
- Table 135-3. Minimum steel in slabs and lids.
- Table 135-4. Minimum steel in walls.
- Table 135-5. Tank wall design loads.
- Table 135-6. Reinforced concrete tank walls.
- Table 135-7. Beams at top of tank walls.
- Table 135-8. Tank lid design loads.
- Table 135-9. Reinforced tank lids; no vehicles.
- Table 135-10. Heavy tank lid designs.
- Table 135-11. Minimum member width.
- Table 135-12. Slotted floor design loads.
- Table 135-13. Selected slat designs.
- Table 135-14. Girders to support slotted floors.
- Table 135-15. Girders with maximum efficient reinforcing.
- Table 135-16. Unreinforced concrete masonry columns and footings.
- Table 135-17. Unreinforced square concrete footings.
- Table 135-18. Reinforced concrete columns and footings.
- Table 135-19. Superimposable load on slats and beams.

Reinforced with Welded Wire Fabric

- Table 135-20. Minimum welded wire fabric steel in walls.
- Table 135-21. Minimum welded wire fabric steel in slabs.
- Table 135-22. Wire size comparison.
- Table 135-23. Sectional areas of welded wire fabric.
- Table 135-24. Typical stock items.
- Table 135-25. Sectional areas of steel reinforcing.
- Table 135-26. Reinforced concrete tank walls; vertical reinforced design.
- Table 135-27. Reinforced concrete tank lids for NO vehicle traffic; one-way slab design adequate for load listed plus dead weight of slab; sectional area of steel required, in.²/ft.
- Table 135-28. Heavy tank lid designs for 2-5000 lb loads 4' oc plus dead weight of slabs. Sectional area of steel required, in.²/ft.

PROCEDURE SUMMARY

Materials

Obtain materials that meet or exceed the strength specifications of Table 1.

NOTE: Bar spacings are given to 1/10"; the designer can select designed rounding.

Tank Design

Tank Walls Fig 2

Determine soil characteristics and choose the design load from Table 5.

Determine desired Tank Depth.

Select vertical steel from Table 6.

Select horizontal steel (min temperature and shrinkage steel) from Table 4.

Beams At The Top Of Tank Walls

Determine the distance between lateral restraints at the top of the tank wall.

Select extra reinforcing needed from Table 7 for the tank depth and design load, trying first a beam thickness equal to that of the wall itself before trying larger thicknesses.

Tank Lids

Determine desired span of the slab.

Determine the design load from Table 8 and Fig 1 for no vehicle traffic, or assume given tractor or manure wagon load.

Select principal reinforcing steel from Table 10 for the given tractor of manure wagon load or from Table 9 for the design snow and/or animal traffic load.

Select temperature and shrinkage steel for the chosen slab thickness from Table 3.

Slotted Floor and Support System Design

Slotted Floor (Fig 3)

Determine load on slat from Table 12, second column.

Determine length of slat (usually not over 10').

Select slat design from Table 13.

Floor-Support Girders (Fig 3)

Determine load per foot of girder.

Determine length of girder (usually not over 10').

Select girder design from Table 14 or 15.

Columns (Fig 4)

Determine column load.

Determine column height (usually not over 8').

Select column design from Table 16 or 18.

Column Support (Fig 4)

Select adequate footing for column load from Table 16, 17 or 18.

The wall and lid loads used in developing the tables are from ASAE R345, Design of Farm Waste Storage Tanks. Refer to the Recommendation for additional information on location, safety features, etc. Slat and beam loads came primarily from the Canadian Farm Building Code and are those proposed for an ASAE Recommendation.

One section of ACI 318-71 has not been rigidly followed. Paragraph 11.1.1(c) limits beams to 10" deep without minimum shear reinforcement. Paragraph 11.1.1(d) states that if the allowable shear stress is cut in half, minimum shear reinforcement is not required. The Commentary explains that these requirements, not in ACI 318-63, are for ductility. Ductility helps provide warning of failure and resistance to unexpected tension or catastrophic loads. Beams for slotted floors are supporting a relatively large dead load, almost one-half the total

load in most cases, and are not subject to large, unexpected loads. Therefore, the beams in Tables 14, 15 and 19 use the full allowable shear stress for depths of up to 15" as allowed in ACI 318-63.

Hydrogen sulphide, H_2S , is given off from anaerobic waste storages. Where a tank has air over the liquids and condensation on the underside of the lid, H_2S may lead to sulphuric acid, H_2SO_4 . There is no general preventative to attack by the acid available to the farm tank designer or owner. Cement low in tri-calcium aluminate is naturally available in some areas, and has some sulphate resistance, as does Type II cement, which is apt to be available in areas with water supplies naturally high in sulphates. Specification of a high quality air-entrained concrete is perhaps the best solution available to the engineer.

Deformed Bars

Table 135-1. Allowable stresses, ultimate design.

Concrete		
Compressive strength	f'_c	3,500 psi
Punching shear	$3.4(f'_c)^{1/2}$	201 psi
Beam shear	$1.7(f'_c)^{1/2}$ or $0.85 \left(1.9(f'_c)^{1/2} + 2500 \frac{(A_s)(V_u)}{(B)(M_u)} \right)$	100 psi
Flexural tension	$3.25(f'_c)^{1/2}$	192 psi
Elasticity	$(1837)(33)(f'_c)^{1/2}$	3.6×10^6 psi
Steel		
Tension yield point	f_y	36,000 psi
Elasticity		2.9×10^7 psi
Development length	$\frac{(0.04)(A_b)(f_y)}{f'_c}$ but not less than $(0.0004)(d_b)(f_y)$ or 12"	

Table 135-2. Reinforcing steel.

No.	Area in. ²	Diam. in.	Weight lb/ft	Perimeter in.	Development Length in.
3	0.11	0.375	0.376	1.178	12.0
4	0.20	0.500	0.668	1.571	12.0
5	0.31	0.625	1.043	1.963	12.0
6	0.44	0.750	1.502	2.356	12.0
7	0.60	0.875	2.044	2.749	14.6
8	0.79	1.000	2.670	3.142	19.3
9	1.00	1.128	3.400	3.544	24.4
10	1.27	1.270	4.303	3.990	30.9
11	1.56	1.410	5.313	4.430	38.0

Bar spacing = (12)(bar area)/steel area required—in²/ft; e.g. if $A_s = 0.18$ in 6" slab, #3 bars (0.11 in²): spacing = $12 \times 0.11 / 0.18 = 7.33"$; To convert from one bar size to another: New bar spacing = (new bar area) (old bar spacing) / (old bar area), e.g. #4 bars (0.20 in²) to replace #3's in example above: #4 spacing = $(0.20)(7.33) / (0.11) = 13.33"$

Table 135-3. Minimum steel in slabs and lids.

Temperature and shrinkage steel:
Area = 0.002bt both ways

Slab Thickness	4"	5"	6"	7"
Min. A_s /ft	0.096	0.120	0.144	0.168
Bar Size	#3	#3	#3	#3
Bar Spacing	13.8"	11"	9.2"	7.8"
OR				
Bar Size	#4	#4	#4	#4
Bar Spacing	18.0"	18.0"	16.7"	14.3"

Slab Thickness	8"	9"	10"	11"	12"
Min. A_s /ft	0.192	0.216	0.240	0.264	0.288
Bar Size	#3	#4	#4	#4	#4
Bar Spacing	6.9"	11.0"	10.0"	9.1"	8.3"
OR					
Bar Size	#4	#5	#5	#5	#5
Bar Spacing	12.5"	17.2"	15.5"	14.1"	12.9"

Bar spacing = (bar area) / ((thickness)(minimum steel ratio))

NOTE: Maximum spacing of bars is the lesser of 3 times the slab thickness or 18".

Table 135-4. Minimum steel in walls.

Temperature and shrinkage steel:

Area = 0.0025bt horizontally 0.0015bt vertically

Wall Thickness, inches	4"	5"	6"	7"
Vert. min. A_s /ft	0.0720	0.0900	0.1080	0.1260
bar size	#3	#3	#3	#3
bar spacing	18.0"	14.7"	12.2"	10.5"
Horiz. min. A_s /ft	0.1200	0.1500	0.1800	0.2100
bar size	#3	#3	#3	#4
bar spacing	11.0"	8.8"	7.3"	11.4"

Wall Thickness, inches	8"	9"	10"	11"	12"
Vert. min. A_s /ft	0.1440	0.1620	0.1800	0.1980	0.2160
bar size	#3	#3	#3	#4	#4
bar spacing	9.2"	8.2"	7.3"	12.1"	11.1"
Horiz. min. A_s /ft	0.2400	0.2700	0.3000	0.3300	0.3600
bar size	#4	#4	#4	#5	#5
bar spacing	10.0"	8.9"	8.0"	11.3"	10.3"

NOTE: Maximum spacing of bars is the lesser of 5 times the slab thickness or 18".

TANK DESIGN

Assumptions

Tank Walls—Vertically Reinforced

Ultimate Strength Design (ACI 318-71).

One-way slab design assumes pinned ends and continuous lateral support at top and bottom.

Maximum vertical steel spacing is 3 times the wall thickness or 18". (Arbitrarily set at 12" in the Table)

Triangular pressure distribution of the given design loads, except 100 psf vehicle surcharge.

Load factor = 1.7 on the design loads.

Allowable deflection = $L/180$.

Wall steel cover = $1\frac{1}{2}$ " for #5 or smaller.

= 2" for #6 or larger.

Beams At Top Of Tank Walls

Ultimate Strength Design (ACI 318-71).

Deflection was not restricted because the additional strength of the horizontal temperature and shrinkage steel was ignored in the design procedure.

Load factor = 1.7 on the triangular wall load to determine reactions carried by the beam.

Specified vertical and horizontal wall steel extends through the beam, so no minimum steel % is required for the beam.

Tank Lids—Reinforced across span

Tank lids for NO vehicle traffic

Ultimate Strength Design (ACI 318-71).

One-way slab design assumes pinned ends at each sidewall.

Load factors = 1.7 on tabulated loads and 1.4 on deadweight of the slab.

Shear and an allowable deflection of $L/180$ checked for.

Lid steel cover = $1\frac{1}{2}$ " for #5 or smaller.

= 2" for #6 or larger.

Tank lids to support large tractor or manure wagon.

Ultimate Strength Design (ACI 318-71).

One-way slab design assumes pinned ends at each side wall.

Design load = 2–5000 lb loads 4' oc plus deadweight of slab.

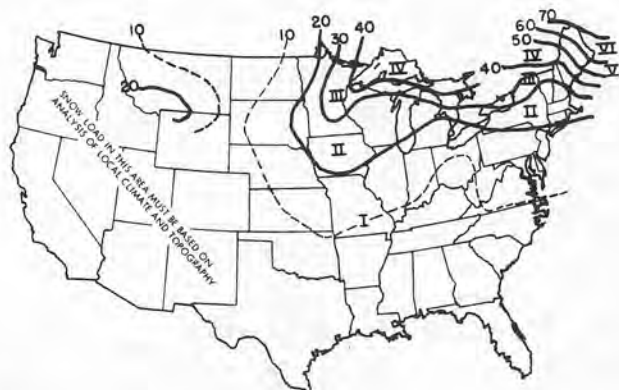


Fig 135-1. Snow load zone map.

Load factor = 1.7 on axle load and 1.4 on deadweight of slab.

Design moment determined from the AASHTO equation for bridge decks:

$$\text{Moment} = \frac{(1.7)(L+2)P}{32} + \frac{(1.4)WL^2}{8}$$

L = span, ft; P = axle load of 10,000 lb; W = deadweight of the slab.

Only bending moment checked.

Lid steel cover = $1\frac{1}{2}$ " for #5 or smaller.

= 2" for #6 or larger.

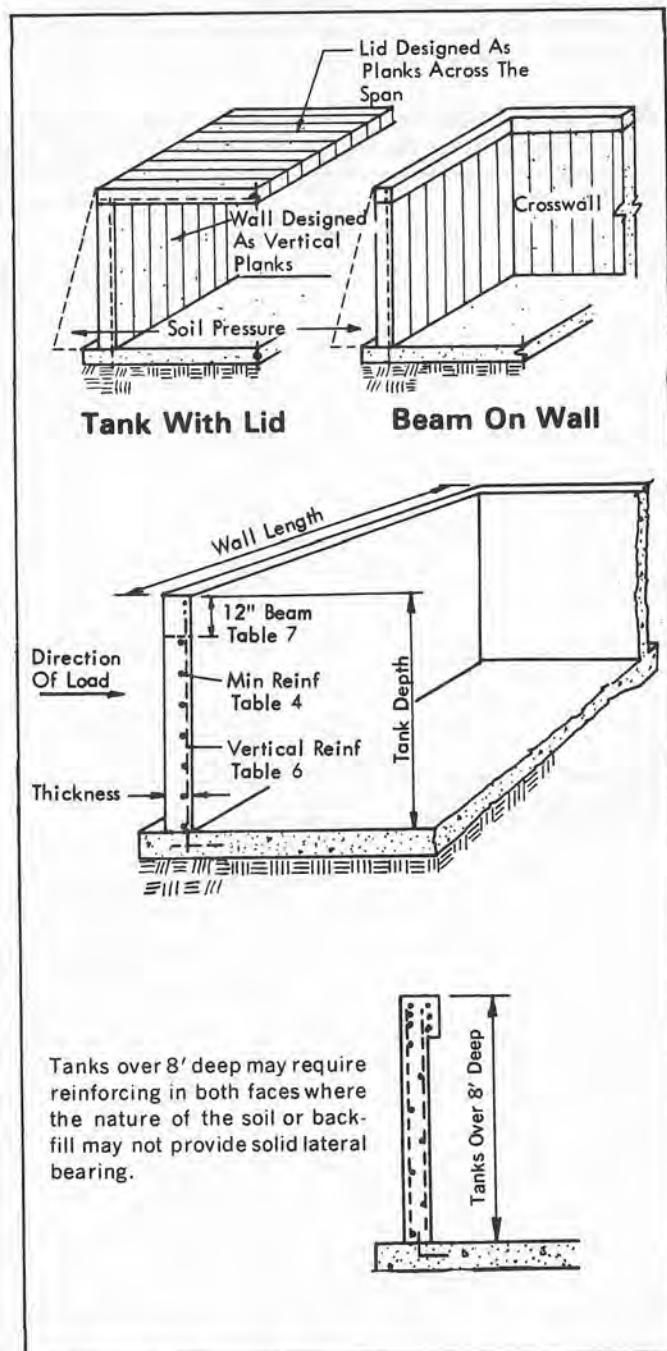


Fig 135-2. Manure tank design assumptions.

Tank Walls**Table 135-5. Tank wall design loads.**

Soil Characteristics	Design Load (inward)
Well-drained	15 psf/ft.
Moderate drainage	30 psf/ft.
High water table	60 psf/ft.

(Also use 60 psf in both directions for partitions and outward for walls above grade.)

Note: In the tables "psf/ft" is abbreviated with its dimensional equivalent "pcf".

ASAE R345 includes a design load of 110 psf/ft for saturated fine sand. This soil type requires major modification of designs to allow for flotation, a structural floor, serious drainage and settling problems, and possible restrictions by building or

other public authorities. Design elements are not included here.

Walls over 8' deep, constructed where the nature of the soil or backfill may not provide solid lateral bearing should also be reinforced in the outside face to resist full lateral hydraulic pressure (60 psf/ft) from stored liquid in the tank.

A 100 psf surcharge on the hydrostatic wall load is recommended where the installation or operation requires the movement of heavy equipment within 5 ft of the tank walls; see the bottom half of Table 6.

The wall designs assume continuous lateral support at the top and bottom. The upper 12" of the wall may be reinforced as given in Table 7, to provide this lateral support and carry wall loads to a pilaster, partition, endwall, or cross beam.

Table 135-6. Reinforced concrete tank walls; vertical reinforced design; bar size and spacing, inches.

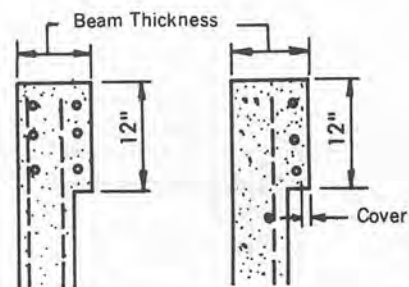
Tabulated reinforcing is vertical; minimum reinforcing (Table 4) is horizontal.

Hydrastatic Load	Wall Thickness	Load, pcf	Bar Size		Tank Depth		Spacing, Inches			
			6'	7'	8'	9'	10'	12'	14'	16'
	6"	15	3,12.2"	3,12.2"	3,12.2"	3,12.2"	3, 9.7"	4,10.0"	5, 9.6"	-
		30	"	"	3, 9.4"	4,12.0"	4, 8.6"	6, 9.4"	-	-
		60	3,11.2"	3, 7.0"	4, 8.4"	6,11.2"	7,10.9"	-	-	-
	7"	15	3,10.5"	3,10.5"	3,10.5"	3,10.5"	3,10.5"	3, 6.8"	5,12.0"	6,10.1"
		30	"	"	"	3, 8.1"	4,10.7"	5, 9.4"	7,10.0"	-
		60	"	3, 8.6"	4,10.4"	5,11.2"	6,10.3"	8,10.3"	-	-
	8"	15	3, 9.2"	3, 9.2"	3, 9.2"	3, 9.2"	3, 9.2"	3, 8.1"	4, 9.2"	5, 9.4"
		30	"	"	"	3, 7.0"	5,11.3"	5,11.3"	6, 9.1"	8,10.6"
		60	"	"	3, 6.8"	4, 8.6"	5, 9.7"	7, 9.7"	9, 9.7"	-
	9"	15	3, 8.2"	3, 8.2"	3, 8.2"	3, 8.2"	3, 8.2"	3, 8.2"	4,10.7"	5,11.0"
		30	"	"	"	"	3, 8.1"	4, 8.4"	6,10.7"	7, 9.6"
		60	"	"	3, 7.9"	4,10.0"	5,11.3"	7,11.5"	9,11.7"	-
	10"	15	3, 7.3"	3, 7.3"	3, 7.3"	3, 7.3"	3, 7.3"	3, 7.3"	3, 6.7"	4, 8.1"
		30	"	"	"	"	"	4, 9.6"	5, 9.3"	7,11.1"
		60	"	"	"	4,11.4"	4, 8.3"	6, 9.7"	8,10.8"	10,11.2"
	11"	15	4,12.1"	4,12.1"	4,12.1"	4,12.1"	4,12.1"	4,12.1"	4,12.1"	4, 9.1"
		30	"	"	"	"	"	4,10.8"	5,10.4"	6, 9.3"
		60	"	"	"	"	4, 9.3"	6,11.0"	7, 9.3"	9,10.2"
	12"	15	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4,10.0"
		30	"	"	"	"	"	4,11.1"	5,11.6"	6,10.4"
		60	"	"	"	"	4,10.3"	5, 9.1"	7,10.4"	9,11.4"
Hydrastatic Load + 100 psf Surcharge For Vehicle Load	6"	15	3,12.2"	3, 9.9"	3, 7.2"	4, 9.8"	5,11.7"	6, 9.0"	-	-
		30	3,10.8"	3, 7.3"	4, 9.4"	5,10.6"	6, 9.9"	-	-	-
		60	3, 7.3"	4, 8.6"	6,11.5"	7,11.0"	-	-	-	-
	7"	15	3,10.5"	3,10.5"	3, 8.9"	3, 6.6"	4, 9.3"	5, 9.1"	7,10.5"	-
		30	"	3, 9.0"	4,11.6"	4, 8.5"	5, 9.9"	7,10.4"	-	-
		60	3, 8.9"	4,10.7"	5,11.4"	6,10.5"	7,10.5"	-	-	-
	8"	15	3, 9.2"	3, 9.2"	3, 9.2"	3, 7.9"	4,11.1"	5,10.9"	6, 9.5"	8,11.9"
		30	"	"	3, 7.6"	4,10.1"	5,11.9"	6, 9.4"	8,10.9"	-
		60	"	3, 7.0"	4, 8.8"	5, 9.8"	6, 9.4"	8, 9.9"	-	-
	9"	15	3, 8.2"	3, 8.2"	3, 8.2"	3, 8.2"	3, 7.1"	4, 8.1"	6,11.2"	7,10.7"
		30	"	"	"	4,11.7"	4, 8.9"	6,11.1"	7, 9.9"	9,11.2"
		60	"	3, 8.1"	4,10.2"	5,11.4"	6,11.2"	8,11.8"	10,11.9"	-
	10"	15	3, 7.3"	3, 7.3"	3, 7.3"	3, 7.3"	3, 7.3"	4, 9.3"	5, 9.7"	6, 9.1"
		30	"	"	"	"	4,10.1"	5, 9.6"	7,11.4"	8,10.3"
		60	"	"	4,11.6"	4, 8.4"	5, 9.7"	7,10.4"	9,10.9"	-
	11"	15	4,12.1"	4,12.1"	4,12.1"	4,12.1"	4,12.1"	4,10.4"	5,10.9"	6,10.3"
		30	"	"	"	"	4,11.3"	5,10.8"	6, 9.5"	8,11.7"
		60	"	"	"	4, 9.4"	5,10.9"	7,11.8"	8, 9.9"	10,10.6"
	12"	15	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4,11.1"	4, 7.8"	6,11.5"
		30	"	"	"	"	"	5,12.0"	6,10.6"	7,10.0"
		60	"	"	"	4,10.4"	4, 7.8"	6, 9.7"	8,11.1"	10,12.0"

Table 135-7. Beams at top of tank walls.

The wall designs assume continuous lateral support at the top and bottom of the walls. The upper 12" of the wall may be reinforced to provide this lateral support and carry wall loads to a pilaster, partition, endwall, or cross beam.

Entries in Table 135-7 are the maximum wall length supported in feet. Reinforcing (Table 135-20) is horizontal.

**6" Beam Thickness**

TANK DEPTH	LOAD pcf	EXTRA REINFORCING IN TOP FOOT					
		1-#4	1-#5	2-#4	2-#5	2-#6	2-#7
4'	15	16	20	23	26	28	-
	30	11	14	16	19	22	25
	60	8	10	11	13	15	17
5'	15	13	16	18	21	25	28
	30	9	11	13	15	17	20
	60	6	8	9	10	12	14
6'	15	11	13	15	17	21	23
	30	7	9	11	12	14	16
	60	5	6	7	8	10	11
7'	15	9	11	13	15	18	20
	30	6	8	9	10	12	14
	60	4	5	6	7	9	10
8'	15	8	10	11	13	15	17
	30	5	7	8	9	11	12
	60	4	5	5	6	7	8
10'	15	6	8	9	10	12	14
	30	4	5	6	7	8	10
	60	-	4	4	5	6	7

8" Beam Thickness

TANK DEPTH	LOAD pcf	EXTRA REINFORCING IN TOP FOOT						
		1-#4	1-#5	2-#4	2-#5	2-#6	2-#7	2-#8
4'	15	20	24	28	-	-	-	-
	30	14	17	20	23	27	28	-
	60	10	12	14	16	19	22	25
5'	15	16	19	22	26	28	-	-
	30	11	14	16	18	22	25	28
	60	8	9	11	13	15	18	20
6'	15	13	16	18	22	26	28	-
	30	9	11	13	15	18	21	24
	60	6	8	9	11	13	15	17
7'	15	11	14	16	19	22	25	28
	30	8	10	11	13	15	18	20
	60	5	7	8	9	11	12	14
8'	15	10	12	14	16	19	22	25
	30	7	8	10	11	13	16	18
	60	5	6	7	8	9	11	12
9'	15	8	11	12	14	17	20	22
	30	6	7	8	10	12	14	16
	60	4	5	6	7	8	10	11
10'	15	8	9	11	13	15	18	20
	30	5	7	8	9	11	12	14
	60	4	4	5	6	7	9	10
12'	15	6	8	9	11	13	15	17
	30	4	5	6	7	9	10	12
	60	-	4	4	5	6	7	8
14'	15	5	7	8	9	11	12	14
	30	4	5	5	6	7	9	10
	60	-	-	4	4	5	6	6
16'	15	5	6	7	8	9	11	12
	30	-	4	5	5	6	8	9
	60	-	-	-	4	4	5	5

10" Beam Thickness

TANK DEPTH	LOAD pcf	EXTRA REINFORCING IN TOP FOOT						
		1-#5	2-#4	2-#5	2-#6	2-#7	2-#8	3-#7
6'	15	19	21	25	28	-	-	-
	30	13	15	18	21	25	28	-
	60	9	10	12	15	17	20	21
7'	15	16	18	22	26	28	-	-
	30	11	13	15	18	21	24	25
	60	8	9	11	13	15	17	18
8'	15	14	16	19	22	26	28	-
	30	10	11	13	16	18	21	22
	60	7	8	9	11	13	15	15
9'	15	12	14	17	20	23	26	28
	30	9	10	12	14	16	18	20
	60	6	7	8	10	11	13	14
10'	15	11	12	15	18	21	24	25
	30	8	9	11	12	15	17	18
	60	5	6	7	9	10	12	12
12'	15	9	10	12	15	17	20	21
	30	6	7	9	10	12	14	15
	60	4	5	6	7	8	10	10
14'	15	8	9	11	13	15	17	18
	30	5	6	7	9	10	12	12
	60	4	4	5	6	7	8	8
16'	15	7	8	9	11	13	15	15
	30	5	5	6	8	9	10	11
	60	-	4	4	5	6	6	6

12" Beam Thickness

TANK DEPTH	LOAD pcf	EXTRA REINFORCING IN TOP FOOT						
		1-#5	2-#4	2-#5	2-#6	2-#7	2-#8	3-#7
8'	15	15	18	21	25	28	-	-
	30	11	12	15	18	21	24	25
	60	7	9	10	12	14	16	18
9'	15	14	16	19	22	26	28	-
	30	10	11	13	16	18	21	22
	60	7	8	9	11	13	15	16
10'	15	12	14	17	20	23	27	28
	30	9	10	12	14	16	19	20
	60	6	7	8	10	11	13	14
12'	15	10	12	14	17	19	22	24
	30	7	8	10	12	14	16	16
	60	5	6	7	8	9	11	12
14'	15	9	10	12	14	17	19	20
	30	6	7	8	10	12	13	14
	60	4	5	6	7	8	9	10
16'	15	7	9	10	12	14	16	18
	30	5	6	7	9	10	12	12
	60	-	4	5	6	7	8	8

Tank Lids

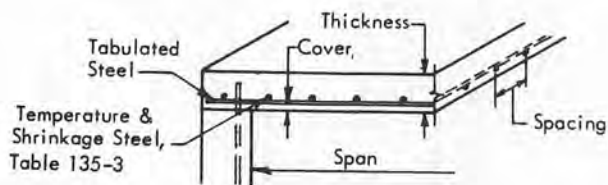


Table 135-8. Tank lid design loads.

Loading Condition	Design Load
human or poultry traffic	40 psf
livestock traffic or up to 15" of soil cover	150 psf
outdoor tanks with no livestock or vehicle traffic	40 psf + snow load on ground from Fig 1.

Table 135-9. Reinforced concrete tank lids for NO vehicle traffic; one-way slab design adequate for load listed plus dead weight of slab; bar size and spacing.

Lid Thickness PSF		Bar Size		Lid Span*		Spacing, Inches		Lid Thickness PSF		Lid Span		Lid Thickness PSF		Lid Span		Lid Thickness PSF		Lid Span	
		5'	6'	7'	8'	9'	10'			12'	12'			14'	16'			18'	20'
4"	40	3,13.8"	3,13.8"	3,10.3"	3, 7.8"	4,11.1"	4, 8.9"	-	8"	40	4,11.1"	4, 8.1"	5, 9.5"	6, 9.7"	-	-	-	-	
	50	"	3,12.5"	3, 9.1"	3, 6.9"	4, 9.8"	4, 7.8"	-		50	4,10.2"	5,11.5"	6,11.4"	6, 8.9"	-	-	-	-	
	60	"	3,11.2"	3, 8.2"	4,11.3"	4, 8.8"	5,10.9"	-		60	4, 9.5"	5,10.7"	6,10.6"	7,11.3"	-	-	-	-	
	70	"	3,10.2"	3, 7.4"	4,10.2"	4, 7.9"	-	-		70	4, 8.8"	5,10.0"	6, 9.9"	7,10.5"	-	-	-	-	
	80	3,13.6"	3, 9.3"	3, 6.8"	4, 9.3"	5,11.2"	-	-		80	4, 8.3"	5, 9.4"	6, 9.2"	7, 9.8"	-	-	-	-	
	90	3,12.5"	3, 8.6"	4,11.4"	4, 8.6"	-	-	-		90	4, 7.8"	6,11.5"	7,11.8"	-	-	-	-	-	
	100	3,11.6"	3, 8.0"	4,10.5"	4, 7.9"	-	-	-		100	5,11.4"	6,10.8"	7,11.1"	-	-	-	-	-	
5"	40	3,11.0"	3,11.0"	3,11.0"	3, 9.8"	3, 7.7"	4,11.3"	5,12.0"	9"	40	4,11.0"	4, 8.6"	5,10.2"	6,10.5"	7,11.5"	7, 9.4"	-		
	50	"	"	"	3, 8.8"	3, 6.9"	4,10.2"	5,10.8"		50	"	4, 8.0"	5, 9.4"	6, 9.8"	7,10.7"	-	-	-	
	60	"	"	3,10.6"	3, 8.0"	4,11.5"	4, 9.2"	6,11.6"		60	4,10.2"	5,11.6"	5, 8.8"	6, 9.1"	7, 9.9"	-	-	-	
	70	"	"	3, 9.7"	3, 7.4"	4,10.5"	4, 8.4"	-		70	4, 9.6"	5,10.9"	6,10.9"	7,11.6"	7, 9.3"	-	-	-	
	80	"	"	3, 8.9"	3, 6.8"	4, 9.7"	4, 7.8"	-		80	4, 9.0"	5,10.2"	6,10.2"	7,10.9"	8,11.5"	-	-	-	
	90	"	"	3, 8.3"	4,11.4"	4, 9.0"	5,11.1"	-		90	4, 8.5"	5, 9.6"	6, 9.6"	7,10.3"	-	-	-	-	
	100	"	3,10.6"	3, 7.7"	4,10.7"	4, 8.3"	5,10.4"	-		100	4, 8.1"	5, 9.1"	6, 9.1"	7, 9.7"	-	-	-	-	
6"	40	3, 9.2"	3, 9.2"	3, 9.2"	3, 9.2"	3, 9.0"	3, 7.3"	4, 9.1"	10"	40	4,10.0"	4, 9.1"	5,10.8"	6,11.2"	6, 9.0"	7,10.1"	8,11.1"		
	50	"	"	"	"	3, 8.2"	3, 6.6"	4, 8.2"		50	"	"	4, 8.5"	5,10.0"	6,10.5"	7,11.5"	7, 9.4"	-	
	60	"	"	"	"	3, 7.5"	4,11.0"	5,11.7"		60	"	"	4, 8.0"	5, 9.4"	6, 9.8"	7,10.8"	8,11.6"	-	
	70	"	"	"	"	3, 6.9"	4,10.1"	5,10.8"		70	"	"	5,11.6"	5, 8.8"	6, 9.2"	7,10.1"	8,10.9"	-	
	80	"	"	"	"	3, 8.2"	4,11.7"	4, 9.4"		80	4, 9.7"	5,11.0"	6,11.1"	6, 8.7"	7, 9.5"	8,10.2"	-	-	
	90	"	"	"	"	3, 7.6"	4,10.9"	4, 8.8"		90	4, 9.2"	5,10.4"	6,10.5"	7,11.2"	8,11.9"	8, 9.7"	-	-	
	100	"	"	"	"	3, 7.1"	4,10.2"	4, 8.2"		100	4, 8.7"	5, 9.9"	6,10.0"	7,10.7"	8,11.2"	-	-	-	
7"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	11"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	8,11.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	8,10.3"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	8, 9.7"	
	80	"	"	"	"	"	3, 7.4"	4,10.8"		80	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	9,11.6"	
	90	"	"	"	"	"	3, 6.9"	4,10.1"		90	"	"	5,11.1"	6,11.3"	6, 8.9"	7, 9.7"	8,10.5"	9,11.0"	
	100	"	"	"	"	"	4,11.8"	4, 9.5"		100	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	-	
8"	40	3, 6.9"	3, 6.9"	3, 6.9"	3, 6.9"	3, 6.9"	3, 6.9"	4,11.1"	12"	40	4, 8.3"	4, 8.3"	5,11.7"	5, 9.2"	6,10.0"	7,11.2"	7, 9.3"		
	50	"	"	"	"	"	"	4,10.2"		50	"	"	"	5,11.0"	5, 8.6"	6, 9.4"	7,10.5"	8,11.6"	
	60	"	"	"	"	"	"	4, 9.5"		60	"	"	"	5,10.4"	6,11.0"	6, 8.9"	7, 9.9"	8,10.9"	
	70	"	"	"	"	"	"	4, 8.8"		70	"	"	"	5, 9.8"	6,10.4"	7,11.4"	7, 9.4"	8,10.3"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	4, 7.9"	5, 9.3"	6, 9.4"	7,10.9"	8, 9.8"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.7"	5, 8.9"	6, 9.4"	7,10.3"	8,11.2"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
9"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	13"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
10"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	14"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
11"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	15"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
12"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	16"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
13"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	17"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
14"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	18"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
15"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	19"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		50	"	"	"	4, 8.9"	5,10.5"	6,11.1"	6, 8.9"	7,10.0"	
	60	"	"	"	"	"	"	4, 8.6"		60	"	"	"	4, 8.4"	5, 9.9"	6,10.5"	7,11.5"	7, 9.4"	
	70	"	"	"	"	"	"	4, 8.0"		70	"	"	"	4, 7.9"	5, 9.4"	6, 9.9"	7,10.8"	8,11.7"	
	80	"	"	"	"	"	"	4, 8.3"		80	"	"	"	5,11.7"	5, 8.9"	6, 9.3"	7,10.2"	8,11.0"	
	90	"	"	"	"	"	"	4,11.3"		90	"	"	"	5,11.1"	6,11.5"	6, 9.0"	7, 9.9"	8,10.6"	
	100	"	"	"	"	"	"	4,10.7"		100	"	"	"	5,10.5"	6,10.8"	7,11.5"	7, 9.2"	8, 9.9"	
16"	40	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	3, 7.8"	4,10.2"	20"	40	4, 9.1"	4, 9.1"	5,11.2"	5, 8.8"	6, 9.5"	7,10.7"	8,11.7"		
	50	"	"	"	"	"	"	4, 9.3"		5									

*All 4' wide covers require only minimum reinforcing, except 4" thickness, 150 psf = #3,13.4".

Table 135-10. Heavy tank lid designs for 2-5000 lb loads 4' oc plus dead weight of slabs.

Span	Slab Thickness						
	5"	6"	7"	8"	9"	10"	11"
4'	#5, 9.9"	#4, 8.3"	#4,10.2"	#4,12.0"	#4,11.0"	#4,10.0"	#4, 9.1"
5'	#6, 9.7"	#5,10.7"	#4, 8.5"	#4, 9.9"	"	"	"
6'	7,11.2"	6,11.4"	5,11.2"	4, 8.4"	4, 9.6"	"	"
7'	7, 9.6"	6, 9.8"	5, 9.6"	5,11.3"	4, 8.3"	4, 9.3"	"
8'	#8,10.9"	#7,11.7"	#6,10.8"	#5, 9.9"	#5,11.2"	#4, 8.1"	#4, 8.9"
9'	8, 9.5"	7,10.3"	6, 9.5"	6,11.3"	5, 9.9"	5,11.0"	4, 7.8"
10'	9,10.5"	8,12.0"	7,11.5"	6,10.1"	6,11.6"	5, 9.7"	5,10.7"
12'	-	8, 9.6"	7, 9.3"	7,11.1"	6, 9.3"	6,10.4"	6,11.5"
14'	-	#9, 9.9"	#8,10.1"	#7, 9.1"	#7,10.5"	#7,11.7"	#6, 9.4"
16'	-	10,10.4"	9,10.6"	8,10.1"	8,11.5"	7, 9.8"	7,10.7"
18'	-	-	10,11.4"	9,10.8"	8, 9.8"	8,10.9"	8,11.9"
20'	-	-	-	10,11.8"	9,10.6"	9,11.9"	8,10.2"
22'	-	-	-	#10,10.2"	#10,11.7"	#9,10.3"	#9,11.2"
24'	-	-	-	-	10,10.2"	10,11.4"	9, 9.8"
26'	-	-	-	-	-	10,10.0"	10,11.8"

SLAT, AND FLOOR OR LID SUPPORT, DESIGN

Assumptions

Reinforced Concrete Slats and Girders

Ultimate Stress Design (ACI 318-71).

Clear distance between bars; not less than bar diameter, 1", nor 1 1/3 times max size of coarse aggregate.

Cover = 1 1/2" for #5 or smaller
= 2" for #6 or larger

Load factors = 1.4 on beam's weight and 1.7 on tabulated load.

Allowable Deflection = $L/180$

Maximum Steel Percentage = 3.73%

Minimum Steel Percentage = 0.56%

The allowable load is reduced by 25% for steel percentages less than the minimum.

Masonry Columns

Working stress design (Specification for the design and construction of load-bearing concrete masonry, MCMA).

Compressive strength of masonry, $f'_m = 1100$ psi.
Cores filled with grout.

Reinforced Columns; Footings—plain and reinforced

Ultimate stress design (ACI 318-71)

Load factor on all loads = 1.7

Minimum column steel area = 1% of column area

Column steel cover = 1 1/2" for #5 or smaller
= 2" for #6 or larger

4 bars per square tied column, minimum

6 bars per round spiral column, minimum

Modified R reduction factors for slenderness

Space #3 ties no greater than 16 longitudinal bar diameters, least dimension of the column, or 16".

Soil bearing = 3000 psf

Cover between soil and footing steel = 3"

Maximum bar spacing = 18" or 3 times the footing thickness.

Table 135-11. Minimum member width, inches.

Bar	Diameter	1 Bar	2 Bars	3 Bars
# 3	.375"	3.375"	4.750"	6.125"
4	.500	3.500	5.000	6.500
5	.625	3.625	5.250	6.875
6	.750	4.750	6.500	8.250
7	.875	4.875	6.750	8.625
8	1.000	5.000	7.000	9.000
9	1.128	5.128	7.384	9.640
10	1.270	5.270	7.810	10.350
11	1.410	5.410	8.230	11.050

Clear distance between bars not less than bar diameter, 1" nor 1 1/3 times max course aggregate

SLATS

Table 135-12. Slotted floor design loads.

Livestock	Live Loads for Slat Design plf slat	Live Distributed Loads for Design of Girders and Columns psf floor area
Swine to 50#	50 plf	35 psf
to 200#	100	50
to 500#	170	70
Sheep	120	50
Calves	150	50
Beef, Dairy cattle	250	100

An alternate requirement for slats and slat supports under pigs up to 50 lb, which may dictate design, is one concentrated load of 220 lb (man + pig) located first for maximum moment, then maximum shear.

Fig 135-3. Slotted floor and support system.

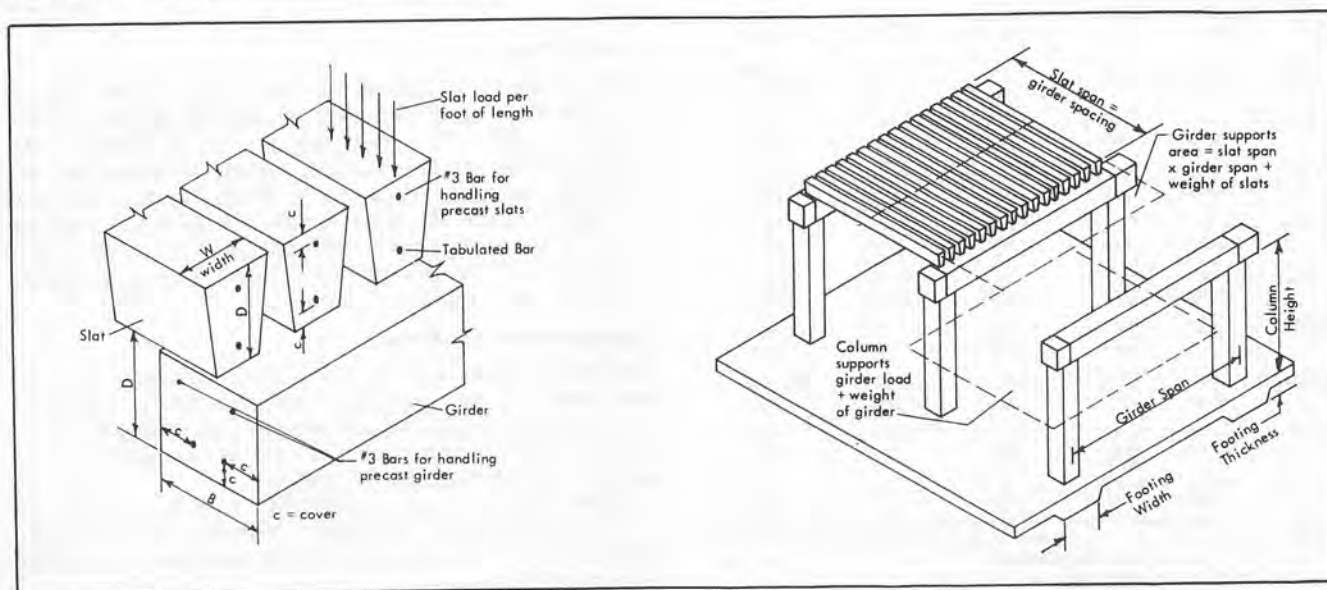


Table 135-13. Selected slat designs.

Width x depth, B x D, inches; reinforcing steel bar size; slat weight, lb/ft.

Slat Span	Slat load per ft of length					
	50	100	120	150	170	250
4' BxD in.	4x4	4x4	4x4	4x4	4x4	4x4
Bar size	#3	#3	#3	#3	#3	#4
Wt, lb/ft	16.7	16.7	16.7	16.7	16.7	16.7
6' BxD	4x4	4x4	4x4 5x5	4x4½ 5x5	4x5 5x5	4x5 5x6
Bar size	#3	#4	#4 #4	#4 #4	#4 #4	#5 #4
Wt	16.7	16.7	16.7 26.1	18.7 26.1	20.8 26.1	20.8 31.3
8' BxD	4x4 5x5	4x5 5x5	4x5 5x5	4x5½ 6x6	4x5½ 5x5½	4x7 5x6
Bar size	#4 #4	#4 #4	#5 #5	#5 #5	#5 #5	#5 #6
Wt	16.7 26.1	20.8 26.1	20.8 26.1	22.9 37.5	22.9 28.6	29.2 31.3
10' BxD	4x5 5x5	4x6 5x5½	5x6 6x6	4x7 6x7	4x7½ 6x6½	5x7 6x7
Bar size	#5 #4	#5 #5	#5 #5	#5 #5	#5 #6	#7 #7
Wt	20.8 26.1	25.0 28.6	31.3 37.5	29.2 43.8	31.2 40.5	36.5 43.8
12' BxD	4x6 5x5½	4x7 5x7	5x7 6x7	5x7 6x7	5x7½ 6x7	5x8 6x8
Bar size	#5 #5	#5 #5	#6 #6	#8 #7	#7 #8	#8 #8
Wt	25.0 28.6	29.2 36.5	36.5 43.8	36.5 43.8	39.0 43.8	41.5 50.0

Design slats and slat supports in farrowing areas for one concentrated load of 250 lb located first for maximum moment, then maximum shear.

Where slats are interconnected between supports so that three or more slats must deflect together, design each span of slat between support and interconnection, and between two interconnections, for the recommended load per unit length of slat. Design the full span of each slat for one-half the recommended load per unit length (an arbitrary recommendation).

Table 135-14. Girders to support slotted floors.

Width x depth (B x D) and number and size of reinforcing bars.

Load/foot of Girder pounds		Beam Span, Feet			
		6'	8'	10'	12'
500 lb	BxD	6"x 6"	6"x 7"	7"x 8"	7"x 9"
	BARS	2#4	2#5	2#6	2#7
600	BxD	6 x 6	6 x 8	7 x 8	7 x10
	BARS	2#5	2#5	2#7	2#8
700	BxD	6 x 6	6 x 9	7 x 9	7 x10
	BARS	2#5	2#5	2#7	2#8
800	BxD	6 x 7	7 x 8	8 x 8	8 x10
	BARS	2#5	2#6	2#8	2#8
900	BxD	6 x 7	7 x 9	7 x 9	9 x10
	BARS	2#5	2#6	2#8	3#7
1000 lb	BxD	6"x 8"	8"x 8"	8"x 9"	9"x10"
	BARS	2#5	2#7	2#8	3#8
1200	BxD	7 x 9	9 x 9	9 x10	9 x11
	BARS	2#5	2#7	2#8	3#8
1400	BxD	7 x 9	9 x10	10 x11	10 x12
	BARS	2#5	2#7	2#8	3#8
1600	BxD	7 x10	9 x11	10 x12	11 x13
	BARS	2#5	2#7	2#8	3#8
1800	BxD	7 x11	10 x11	10 x13	12 x14
	BARS	2#6	3#6	3#7	3#8
2000 lb	BxD	8"x11"	10"x12"	12"x12"	13"x14"
	BARS	2#6	3#6	3#8	3#8
2200	BxD	9 x11	11 x12	12 x13	13 x14
	BARS	2#6	3#6	3#8	3#8
2400	BxD	9 x11	11 x 13	12 x14	14 x15
	BARS	3#5	3#6	3#8	4#8

NOTE: Clear distance between bars in beams and girders is not less than bar diameter, 1", nor 1 1/3 times the size of coarse aggregate.

Design Example

Design a slotted floor system for 200 lb pigs.

Slats

Determine slat length from the building layout, for this example use 8 ft. Determine the design load from Table 12: 100 plf. Select a slat design from Table 13 for 100 plf load and 8 ft span: 4 x 5 with one #4 bar, weighing 20.8 plf.

Girders

Determine the load in plf on the girders. Load on girder, plf = (weight of floor + weight of animals) x girder spacing. Girder spacing equals previously selected slat length (8 ft). Weight of slats (1 sq ft of floor area) = number of slats/ft x wt of slat/ft.

$$\text{The number of slats/ft} = \frac{12}{\text{Slat width} + \text{slot width}}$$

$$\text{Slat width} + \text{slot width}$$

Assume a slot width of 1 in. for the previously selected 4 x 5 slats @20.8 lb/ft.

$$\text{Weight of slats/sq ft of floor area: } \frac{12 \times 20.8}{4 + 1}$$

$$= 49.92 \text{ psf}$$

Use a floor weight of 50 psf. From Table 12 the design floor load for 200 lb pigs is 50 psf. Girder load = (50 psf + 50 psf) x 8 ft = 800 plf. Determine the girder length, which is equal to the column spacing, from the building layout. For this example use 8 ft. From Table 14 select the girder design that supports 800 plf on a 8 ft span. The girder is 7" x 8" with 2#6 bars. The girder may also be selected from Table 15.

Columns and Footings

Determine the column load. Each column supports one end of two girders, and therefore supports the total load on one girder plus the weight of the girder. The total load on one girder equals the girder load/ft x girder length.

$$\text{Total girder load: } (800 \text{ plf}) \times 8 \text{ ft} = 6400 \text{ lb.}$$

The weight of the girder equals the cross-sectional area in sq ft x density of concrete in lb/ft³ x length of the girder.

Table 135-15. Load in plf on girders with maximum efficient reinforcing.

Girder size, B x D, inches; number and size of reinforcing bars; maximum efficient load on girder, lb/ft.

Member width		Size depth		Beam Span, Feet														
				4'		6'		8'		10'		12'		14'		16'		
6"	6"	2#5	1248	2#5	748	2#5	407	2#5	219	2#5	116	2#5	63	2#5	34			
	7		1514		923		525		323		203		116		67			
	8		1809		1081		643		397		263		182		112			
	9		2139		1250		761		470		312		217		155			
	10		2510		1431		879		544		362		252		181			
	11"		2932		1626		997		617		411		287		206			
	12		3414		1836		1115		691		461		322		232			
	13		3971		2063		1233		765		510		357		258			
	14		4622		2310		1351		838		560		392		283			
	15		5392		2578		1469		912		610		427		309			
	7"	7"	2#5	1694	2#5	975	2#6	633	2#7	434	2#7	236	2#8	155	2#8	91		
		8		2036		1188		801		641		401		271		167		
		9		2419		1401		970		788		530		425		268		
		10		2851		1614		1130		934		630		568		393		
		11"		3341		1827		1270		1042		730		664		493		
12			3901		2039		1417		1148		830		761		565			
13			4549		2252		1573		1259		930		857		638			
14			5306		2465		1737		1374		1030		953		710			
15			6138		2678		1911		1495		1130		1040		783			
8"		8"	2#5	2264	2#6	1341	2#7	1050	2#8	809	2#9	540	2#9	321	2#9	198		
		9		2700		1558		1195		1003		807		2#10		566	2#10	359
		10		3192		1791		1347		1123		976		829		535		
		11"		3750		2041		1507		1240		1083		987		738		
		12		4389		2309		1676		1361		1177		1075		857		
		13		5127		2600		1854		1488		1274		1154		976		
	14	2#6	5698		2914		2042		1620		1375		1235		1051			
	15		6631		3255		2241		1757		1479		1318		1119			
	9"	9"	2#5	2981	2#6	1703	2#7	1294	2#8	1022	3#8	956	3#8	602	3#8	381		
		10		3532				1964				1465				1211		1149
		11"		4159		2244		1644		1342		1252		976		727		
		12		4717		2545		1833		1478		1358		1122		837		
		13	2#6	5427		2871		2033		1620		1468		1218		947		
		14		6319		3224		2244		1768		1582		1309		1057		
		15		7367		3607		2467		1922		1700		1402		1167		
10"		10"	3#5	4107	3#5	2336	3#6	1636	3#7	1367	3#8	1182	3#9	1007	3#9	661		
		11"		4807				2660				1836				1512		1333
		12		5609		3010		2047		1664		1450		1318		1032		
		13		6535		3375		2269		1822		1572		1416		1172		
		14		7617		3695		2504		1987		1698		1517		1290		
		15		8898		4015		2753		2159		1828		1622		1376		
		11"	11"	3#5	5216	3#6	2858	3#6	1966	3#7	1615	3#8	1401	3#9	1216	3#10	1083	
			12		6096		3228		2205		1782		1543		1393		1263	
	13		7113		3628		2450		1955		1676		1501		1405			
	14		8301		4061		2708		2136		1814		1612		1497			
	15		9220		4532		2976		2325		1957		1726		1592			
	12"		3#5	6583	3#6	3464	3#7	2514	3#8	2042	3#8	1613	3#9	1417	3#10	1286		
	13			7690		3900		2781		2232		1780		1585		1464		
	14			3#6		8547		4371		3063		2430		1930		1706	1576	
	15					9947		4883		3361		2636		2086		1830	1679	
13"	13"		3#6	7879	3#6	4171	3#7	2960	3#8	2364	3#8	1820	3#9	1613	3#10	1481		
	14			9168		4681		3265		2578		2018		1796		1655		
	15			10683		5235		3588		2801		2215		1935		1766		
	14"			3#6		9790		3#6		4981		3#7		3467		3#8	2725	3#8
15	11418		5435		3814	2965	2219		1986	1848								
15"	15"		3#6	12154	3#7	6137	3#7	4036	3#8	3130	3#9	2603	3#10	2289	3#10	1856		

Weight of $7'' \times 8'' \times 150 \text{ pcf} \times 8 \text{ ft}$
the girder: $\frac{144 \text{ in}^2/\text{ft}^2}{144 \text{ in}^2/\text{ft}^2} = 467 \text{ lb.}$

Total column load: $6400 \text{ lb} + 467 \text{ lb} = 6867 \text{ lb.}$ Assume the column height in this example is 8 ft. Select a column design from Table 16 or 18. Select a column footing design from Tables 16-18.

Masonry Column and Footing

From Table 16 select a masonry column that will support 6,867 lb with an 8 ft height. An 8 x 8 masonry column 8 ft high will support 10,660 lb and is adequate.

Table 16 lists a 21" sq x 5" thick footing for 8,640 lb; Table 17 lists a 19" sq x 4.1" thick footing for 7,500 lb—the latter footing is adequate and cheaper.

Reinforced Column and Footing

From Table 18 select a reinforced column that will support 6,867 lb with an 8 ft height. Either the minimum round or square columns are adequate. The minimum round column is 8" diameter with 6#3 bars and 1.46 in³ of spiral reinforcing/ft of height. The minimum square column is 8" x 8" with 4#4 bars and #3 ties spaced 8" o.c.

The footings in Table 18 are for the maximum allowable load the given column will support, and

Table 135-16. Unreinforced concrete masonry columns and square footings.

Mortar $f'_m = 1100 \text{ psi}$; footing $f'_c = 3500 \text{ psi}$;
Soil pressure = 3000 psf; fill column cores with grout.

Nominal Column Size	Column Height	Allowable Load	Square Footing Width	Depth
8x8 in.	4'	11,405 lb	24"	6"
	6	11,152	24	6
	8	10,660	23	6
	10	9,849	22	6
	12	8,640	21	5
8x16 in.	4'	21,547 lb	33"	10"
	6	21,070	32	9
	8	20,140	32	9
	10	18,608	30	9
	12	16,323	28	8
16x16 in.	4'	44,609 lb	47"	12"
	6	44,495	47	12
	8	44,273	47	12
	10	43,907	46	12
	12	43,362	46	12

are excessively large for this low column load. The previously selected unreinforced footing for the masonry column is adequate for the reinforced column also.

Footing Designs

Masonry Columns

The footings in Table 16 are adequate for the maximum loads each listed column will support.

If the masonry column is not fully loaded, a footing from Table 17, designed for the actual column load, is adequate.

Reinforced Concrete Columns

Each column in Table 18 is given with a matching reinforced footing that will support the column's maximum load.

If a reinforced column is not fully loaded, check for a smaller or unreinforced footing designed for the actual column load:

Footings in Table 16 for 8x8 or 8x16 columns (but not for 16x16 columns) may be used to support the same load from a reinforced column.

Footings in Table 17 may be used for Table 18 columns, and do not require reinforcing if designed for the actual column load.

Table 135-17. Unreinforced square concrete footings.

8" x 8" minimum column size; 3000 psf soil, 3500 psi concrete; load factor = 1.7.

Load, lbs	Size (sq.) inches	Depth inches
5000	15.5	3.0
7500	19.0	4.1
10000	21.9	5.2
12500	24.5	6.1
15000	26.8	7.0
17500	29.0	7.8
20000	31.0	8.5
22500	32.9	9.2
25000	34.6	9.9
27500	36.3	10.5
30000	38.0	11.1
32500	39.5	11.7
35000	41.0	12.3
37500	42.4	12.8
40000	43.8	13.3
42500	45.2	13.8
45000	46.5	14.3
47500	47.8	14.8
50000	49.0	15.2

Figure 135-4. Column and footing designs.

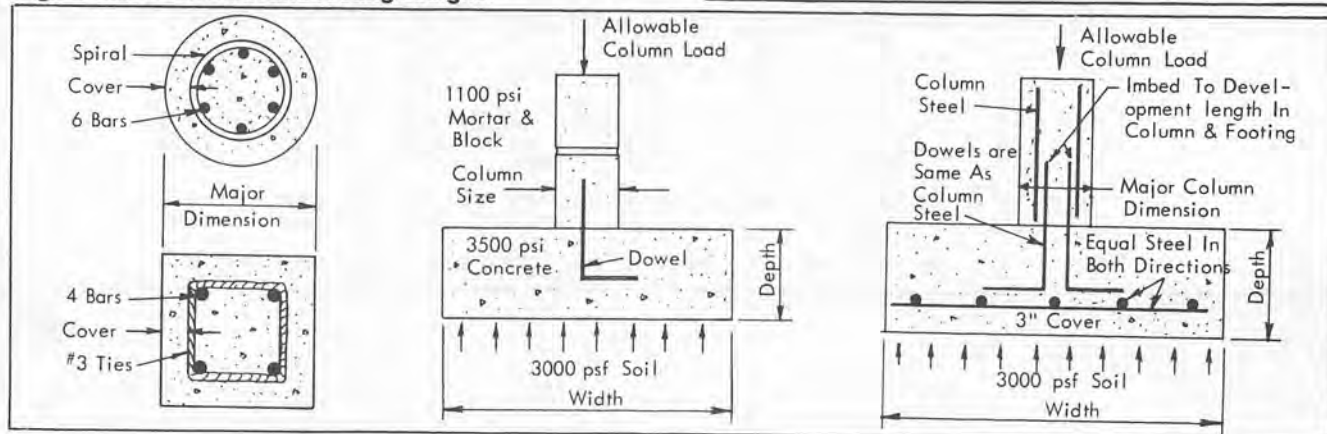


Table 135-18. Reinforced concrete columns and matching footings.

Columns are assumed pinned end and concentrically loaded.

Column Dimension = diameter of a round column or face width of a square one; Column Load = kips, 1000 lb; Spiral Volume = volume of spiral reinforcing per foot of column height, in³/ft; Width = side of a square footing, in.; Depth = footing thickness, in., including 3" cover; As = footing steel area required in both directions, in²; Bars = minimum number, and corresponding size, of equally spaced steel bars in both directions—a larger number of smaller bars may be used to meet the footing As required; #3 ties spacing = maximum vertical spacing, in., between #3 ties in square columns.

Column Dimension		Square Columns Column Height, ft.					#3 ties spacing
		4'	6'	8'	10'	12'	
Square columns with 4-#4 bars							
8"	Column Load:	60.5	57.0	51.2	45.4	39.6	8"
	Footing: Width	54	53	50	47	45	
	Depth	12	12	12	11	10	
	As	2.12	2.00	1.80	1.60	1.40	
	Bars	3#8	3#8	3#8	3#7	3#7	
9	Column Load:	77.9	75.9	69.2	62.6	55.9	8
	Footing: Width	62	61	58	55	52	
	Depth	13	13	13	12	12	
	As	2.73	2.66	2.44	2.21	1.98	
	Bars	4#8	4#8	4#8	4#7	3#8	
Square columns with 4-#5 bars							
8"	Column Load:	65.2	61.4	55.2	48.9	42.6	8"
	Footing: Width	56	55	52	49	46	
	Depth	13	13	12	11	11	
	As	2.28	2.15	1.94	1.73	1.51	
	Bars	4#7	4#7	3#8	3#7	3#7	
9	Column Load:	82.9	80.7	73.7	66.6	59.5	9
	Footing: Width	64	63	60	57	54	
	Depth	14	14	13	13	12	
	As	2.90	2.83	2.59	2.35	2.10	
	Bars	4#8	4#8	4#8	4#7	3#8	
10	Column Load:	102.8	102.8	94.9	87.0	79.1	10
	Footing: Width	71	71	68	65	62	
	Depth	15	15	14	14	13	
	As	3.60	3.60	3.33	3.06	2.79	
	Bars	5#8	5#8	5#8	4#8	4#8	
11	Column Load:	122.1	122.1	116.1	107.6	99.1	10
	Footing: Width	77	77	75	72	69	
	Depth	16	16	15	15	14	
	As	4.28	4.28	4.07	3.78	3.49	
	Bars	6#8	6#8	6#8	5#8	5#8	
Square columns with 4-#6 bars							
8"	Column Load:	70.8	66.7	59.9	53.1	46.3	8"
	Footing: Width	59	57	54	51	48	
	Depth	13	13	12	12	11	
	As	2.48	2.34	2.10	1.87	1.64	
	Bars	4#8	4#7	3#8	3#8	3#7	
9	Column Load:	88.9	86.6	79.0	71.4	63.8	9
	Footing: Width	66	65	62	59	56	
	Depth	14	14	14	13	12	
	As	3.11	3.03	2.77	2.51	2.25	
	Bars	4#8	4#8	4#8	4#8	4#7	
10"	Column Load:	109.1	109.1	100.7	92.3	83.9	10"
	Footing: Width	73	73	70	67	64	
	Depth	15	15	15	14	14	
	As	3.81	3.81	3.53	3.24	2.95	
	Bars	5#8	5#8	5#8	5#8	4#8	
11	Column Load:	128.5	128.5	122.2	113.2	104.3	11
	Footing: Width	79	79	77	74	71	
	Depth	16	16	16	15	15	
	As	4.50	4.50	4.28	3.98	3.67	
	Bars	6#8	6#8	6#8	6#8	5#8	
12	Column Load:	149.8	149.8	145.9	136.3	126.7	12
	Footing: Width	85	85	84	81	78	
	Depth	17	17	17	16	16	
	As	5.24	5.24	5.11	4.78	4.45	
	Bars	7#8	7#8	7#8	7#8	6#8	

Table 135-18. continued.

Column Dimension	Column Height, ft.				Round Columns				Column Height, ft.				spiral volume
	4'	6'	8'	10'	12'	12'	12'	12'	6'	8'	10'	12'	
8"	Round columns with 6-#3 bars				Round columns with 6-#5 (cont)				Round columns with 6-#6 bars				1.79 in ³
	Column Load:	44.6	44.1	40.6	37.0	33.4	33.4	33.4	59.9	66.1	61.1	56.1	
	Footing: Width	47	47	45	43	41	41	41	58	57	55	52	
	Depth	11	11	11	10	10	10	10	13	13	12	12	
	As	1.58	1.56	1.44	1.31	1.19	1.19	1.19	2.46	2.33	2.16	1.99	
9	Column Load:	37	37	37	36	36	36	36	48	47	47	47	3#8
	Footing: Width	58.6	58.6	55.4	51.2	47.1	47.1	47.1	86.6	84.3	78.8	73.2	2.04
	Depth	54	54	52	50	48	48	48	65	64	62	60	
	As	12	12	12	11	11	11	11	14	14	13	13	
	Bars	3#8	3#8	3#8	3#8	3#7	3#7	3#7	4#8	4#8	4#8	4#8	
8"	Round columns with 6-#4 bars				Round columns with 6-#5 bars				Round columns with 6-#6 bars				2.29
	Column Load:	49.1	48.6	44.7	40.8	36.9	36.9	36.9	105.1	104.8	98.7	92.6	
	Footing: Width	49	49	47	45	43	43	43	72	71	69	67	
	Depth	11	11	11	11	10	10	10	15	15	14	14	
	As	1.73	1.72	1.58	1.45	1.31	1.31	1.31	3.70	3.69	3.48	3.27	
9	Column Load:	37	37	37	37	36	36	36	58	58	58	58	5#8
	Footing: Width	63.5	63.5	60.1	55.6	51.0	51.0	51.0	125.5	125.5	120.9	114.2	2.54
	Depth	56	56	54	52	50	50	50	78	78	77	75	
	As	12	12	12	12	11	11	11	16	16	15	15	
	Bars	4#7	4#7	3#8	3#8	3#8	3#8	3#8	6#8	6#8	6#8	6#8	
10	Column Load:	79.8	79.8	77.7	72.6	67.5	67.5	67.5	94.8	92.3	86.3	80.2	2.09 in ³
	Footing: Width	62	62	62	60	57	57	57	68	67	65	63	
	Depth	13	13	13	13	12	12	12	14	14	14	13	
	As	2.81	2.81	2.74	2.57	2.39	2.39	2.39	3.33	3.24	3.04	2.83	
	Bars	4#8	4#8	4#8	4#8	4#7	4#7	4#7	5#8	5#8	4#8	4#8	
11	Column Load:	98.0	98.0	97.8	92.0	86.3	86.3	86.3	113.8	113.5	106.8	100.2	2.35
	Footing: Width	69	69	69	67	65	65	65	74	74	72	70	
	Depth	14	14	14	14	13	13	13	15	15	15	14	
	As	3.45	3.45	3.44	3.25	3.05	3.05	3.05	3.99	3.98	3.76	3.53	
	Bars	5#8	5#8	5#8	5#8	4#8	4#8	4#8	6#8	6#8	5#8	5#8	
12	Column Load:	118.2	118.2	118.2	113.9	107.6	107.6	107.6	134.5	134.5	129.6	122.4	2.61
	Footing: Width	76	76	76	74	72	72	72	81	81	79	78	
	Depth	15	15	15	15	14	14	14	16	16	16	16	
	As	4.16	4.16	4.16	4.01	3.80	3.80	3.80	4.72	4.72	4.55	4.45	
	Bars	6#8	6#8	6#8	6#8	5#8	5#8	5#8	6#8	6#8	6#8	6#8	
8"	Round columns with 6-#5 bars				Round columns with 6-#5 bars				Round columns with 6-#5 bars				1.54 in ³
	Column Load:	55.0	54.4	50.0	45.6	41.2	41.2	41.2	81	81	79	78	
	Footing: Width	52	52	49	47	45	45	45	16	16	16	16	
	Depth	12	12	11	11	11	11	11	16	16	16	16	
	As	1.93	1.91	1.76	1.61	1.46	1.46	1.46	4.72	4.72	4.55	4.45	
8"	Column Load:	38	38	37	37	37	37	37	68	68	68	68	6#8

Table 135-19. Superimposable load on slats and beams, lb/ft.

2 Bars per Beam

SPAN ft H		NO. 3										NO. 4										NO. 5									
		4	5	6	7	8	9	10	4	5	6	7	8	9	10	5	6	7	8	9	10	12									
6		6.0	683	426	286	202	147	110	83	1114	751	512	368	274	210	164	958	748	541	407	310	219	116								
7		7.0	*630	390	260	181	130	95	70	1377	949	648	466	348	268	210	1149	923	697	525	407	323	203								
8		8.0	756	469	313	219	158	116	86	1671	1147	784	565	423	325	255	1355	1081	853	643	499	397	263								
9		9.0	882	548	366	257	185	137	102	1999	1345	920	663	497	383	301	1580	1250	1008	761	551	470	312								
10		10.0	1008	627	419	294	213	157	118	2370	1543	1056	762	571	440	347	1826	1431	1144	879	683	544	362								
11		11.0	1134	705	472	332	241	178	133	2753	1741	1192	860	645	498	392	2095	1626	1319	997	776	617	411								
12		12.0	1260	784	525	369	268	199	149	*2284	1439	980	704	524	401	313	2392	1836	1475	1115	868	691	461								
13		13.0	1386	863	578	407	296	220	165	2517	1586	1081	776	579	443	346	2720	2063	1631	1233	960	765	510								
14		14.0	1512	941	632	445	323	240	181	2750	1734	1182	849	633	485	379	3085	2310	1786	1351	1052	838	560								
15		15.0	1638	1020	685	482	351	261	197	2983	1881	1283	922	687	527	412	3494	2578	1942	1469	1144	912	610								
7		7.0	629	387	256	177	125	90	65	1515	954	650	466	347	265	207	1284	975	705	530	410	324	211								
8		8.0	754	465	308	213	152	110	80	1827	1152	785	564	420	322	252	1524	1188	860	647	501	397	261								
9		9.0	879	543	360	250	179	130	95	2139	1349	920	662	494	379	296	1785	1401	1015	764	592	469	309								
10		10.0	1004	621	412	287	206	150	110	2450	1546	1055	759	567	435	341	2071	1614	1170	881	684	542	358								
11		11.0	1129	698	465	324	232	170	125	*2055	1291	876	626	464	352	273	2384	1827	1324	998	775	615	407								
12		12.0	1254	776	517	361	259	189	140	2287	1438	976	698	517	394	305	2728	2039	1479	1115	866	688	455								
13		13.0	1379	854	565	397	286	209	155	2519	1584	1076	770	571	435	337	3110	2252	1634	1233	957	761	504								
14		14.0	1504	932	621	434	313	229	170	2751	1730	1176	841	624	476	369	3535	2465	1789	1350	1049	833	553								
15		15.0	1629	1010	674	471	339	249	185	2984	1877	1276	913	678	517	401	3896	2678	1943	1467	1140	906	602								
8		8.0	750	460	303	208	146	104	73	1834	1154	784	561	417	318	247	1692	1196	864	648	501	395	257								
9		9.0	874	537	354	243	172	123	88	*1593	997	673	478	352	265	203	1990	1408	1018	765	591	467	305								
10		10.0	998	614	405	279	198	142	102	1824	1143	772	549	404	305	234	2315	1620	1172	881	682	539	353								
11		11.0	1122	691	457	315	224	161	116	2056	1288	871	620	457	345	265	2671	1832	1326	997	772	611	401								
12		12.0	1247	768	508	351	250	180	130	2287	1434	970	691	510	385	296	2980	2044	1480	1113	862	683	449								
13		13.0	1371	845	559	387	275	199	144	2518	1579	1069	762	562	425	328	3288	2256	1633	1230	953	755	497								
14		14.0	1495	922	611	423	301	218	158	2750	1725	1168	833	615	466	359	*2673	1827	1316	985	758	596	384								
15		15.0	1619	999	662	459	327	237	172	2981	1871	1267	904	668	506	390	2902	1984	1430	1071	824	648	418								
9		9.0	869	531	347	237	165	115	80	1593	994	669	473	346	259	196	2063	1412	1019	763	588	463	300								
10		10.0	992	607	398	272	190	134	93	1824	1139	767	543	398	298	227	2371	1623	1172	879	678	534	347								
11		11.0	1115	683	448	307	215	152	107	2054	1284	866	613	449	337	257	2678	1834	1325	994	768	605	394								
12		12.0	1239	759	499	342	240	170	120	2285	1429	964	683	501	377	287	2986	2045	1478	1110	857	677	441								
13		13.0	1362	835	549	377	265	188	133	2515	1573	1062	753	553	416	318	*2445	1667	1198	893	685	535	341								
14		14.0	1485	912	600	412	290	206	146	2746	1718	1160	823	605	455	348	2673	1823	1311	978	750	587	374								
15		15.0	1609	988	650	447	315	224	160	2976	1863	1258	894	657	495	378	2902	1980	1424	1063	815	638	408								
SPAN ft H		7	8	9	10	12	14	16		7	8	9	10	12	14	16	7	8	9	10	12	14	16								
7		NO. 6										NO. 7										NO. 8									
7.0		839	633	491	373	202	115	65		986	797	609	434	236	135	78	1001	857	688	491	268	155	91								
8.0		1018	801	623	495	329	156	118		1131	968	803	641	401	236	143	1262	1077	938	781	457	271	167								
9.0		1171	970	755	601	401	280	185		1285	1096	953	788	530	364	227	1421	1215	1058	937	661	425	268								
10.0		1332	1130	887	707	472	331	235		1447	1229	1067	934	630	447	328	1585	1349	1173	1035	795	568	393								
11.0		1504	1270	1019	813	544	382	277		1620	1370	1185	1042	730	519	382	1759	1491	1292	1138	915	664	493								
12.0		1686	1417	1151	919	616	433	315		1803	1518	1309	1148	830	591	435	1944	1640	1417	1245	997	761	565								
13.0		1880	1573	1283	1024	687	484	352		1998	1675	1439	1259	930	662	489	2140	1798	1547	1356	1083	857	638								
14.0		2087	1737	1415	1130	759	535	390		2206	1840	1575	1374	1030	734	542	2349	1964	1684	1472	1171	953	710								
15.0		2308	1911	1547	1236	831	566	428		2428	2014	1718	1495	1130	806	596	2573	2139	1828	1593	1262	1040	783								
8		8.0	1076	811	629	499	330	204	122	1227	1050	821	654	420	247	149	1361	1167	1012	809	483	285	174								
9.0		1289	979	760	604	400	278	192		1402	1195	1002	800	536	378	236	1537	1312	1143	1003	677	447	280								
10.0		1473	1147	892	709	471	328	235		1587	1347	1168	946	636	445	327	1723	1466	1273	1123	810	577	411								
11.0		1669	1315	1023	814	542	378	272		1783	1507	1303	1091	735	519	380	1921	1627	1408	1240	942	672	497								
12.0		1876	1482	1154	919	613	428	308		1991	1676	1444	1237	834	590	433	2131	1796	1550	1361	1075	768	568								
13.0		2097	1650	1285	1024	684	478	345		2213	1854	1592	1382	933	661	485	2354	1975	1699	1488	1127	863	640								
14.0		2333	1818	1416	1129	754	529	382		2450	2042	1747	1523	1032	732	538	2592	2164	1855	1620	1287	959	712								
15																															

Table 135-19. continued.

2 Bars per Beam

	7	8	9	10	12	14	16		7	8	9	10	12	14	16		7	8	9	10	12	14	16
	NO. 9								NO. 10								NO. 11						
8																							
8.0	1423	1214	1057	935	540	321	198																
9.0	1688	1443	1259	1115	807	506	315		1716	1460	1268	1119	903	566	359								
10.0	1876	1598	1389	1227	976	659	471		2048	1735	1503	1324	1065	829	535								
11.0	2074	1760	1526	1345	1083	822	611		2275	1934	1679	1482	1196	987	738								
12.0	2286	1931	1669	1467	1177	945	704		2489	2106	1823	1605	1291	1075	857								
13.0	2510	2111	1818	1594	1274	1057	796		2715	2288	1974	1733	1389	1154	976								
14.0	2749	2301	1975	1727	1375	1137	885		2957	2480	2132	1867	1490	1235	1051								
15.0	3005	2502	2139	1865	1479	1220	981		3214	2682	2297	2007	1595	1318	1119								
9																							
9.0	1802	1540	1342	1188	829	528	332		1931	1642	1427	1259	976	596	377								
10.0	2012	1713	1488	1314	998	712	491		2210	1884	1640	1450	1173	855	555		2279	1932	1674	1474	1186	963	620
11.0	2235	1894	1641	1446	1163	834	615		2434	2067	1794	1582	1275	1012	755		2649	2253	1949	1713	1374	1143	870
12.0	2471	2085	1801	1582	1268	956	710		2672	2260	1955	1720	1382	1150	873		2889	2448	2120	1868	1504	1254	1024
13.0	2722	2287	1968	1725	1377	1078	802		2925	2463	2123	1863	1491	1238	992		3145	2652	2250	2012	1614	1342	1145
14.0	2990	2500	2144	1874	1490	1200	893		3195	2677	2300	2013	1605	1329	1110		3417	2868	2468	2163	1728	1433	1220
15.0	3276	2725	2328	2029	1607	1322	985		3483	2903	2485	2169	1722	1422	1206		3707	3096	2655	2320	1847	1527	1298
10																							
10.0	2149	1828	1588	1401	1013	721	507		2345	1998	1738	1535	1222	875	582		2533	2147	1860	1638	1318	1007	646
11.0	2395	2029	1757	1547	1181	842	623		2593	2200	1908	1682	1355	1031	767		2806	2385	2071	1828	1475	1205	900
12.0	2656	2240	1934	1698	1348	963	713		2856	2413	2086	1834	1472	1187	885		3071	2600	2250	1981	1593	1327	1046
13.0	2934	2463	2119	1856	1481	1084	804		3136	2638	2272	1993	1594	1322	1002		3353	2826	2438	2141	1716	1425	1193
14.0	3230	2699	2313	2021	1606	1205	895		3434	2874	2468	2159	1719	1422	1120		3653	3064	2635	2308	1842	1526	1298
15.0	3547	2948	2517	2192	1735	1326	985		3752	3125	2673	2331	1850	1526	1237		3974	3316	2841	2481	1973	1630	1384
11																							
11.0	2555	2163	1872	1647	1191	847	624		2751	2333	2022	1782	1434	1045	775		2963	2517	2184	1927	1554	1230	917
12.0	2841	2395	2066	1814	1358	967	714		3039	2567	2217	1949	1563	1200	892		3253	2752	2381	2095	1683	1401	1063
13.0	3146	2640	2269	1987	1525	1087	804		3346	2812	2422	2123	1696	1355	1009		3561	2999	2586	2270	1817	1509	1208
14.0	3471	2898	2482	2167	1692	1208	894		3672	3072	2636	2304	1834	1510	1125		3890	3260	2801	2452	1956	1619	1353
15.0	3818	3171	2706	2356	1859	1328	983		4021	3346	2860	2494	1977	1629	1242		4240	3536	3027	2643	2099	1733	1470
12																							
12.0	3026	2550	2199	1929	1363	969	713		3223	2720	2349	2064	1654	1205	896		3435	2904	2511	2209	1773	1441	1074
13.0	3358	2816	2420	2118	1530	1088	802		3556	2987	2571	2253	1798	1363	1012		3770	3173	2724	2399	1919	1592	1219
14.0	3711	3097	2652	2314	1696	1208	891		3911	3269	2804	2450	1948	1517	1128		4127	3456	2968	2597	2069	1712	1364
15.0	4088	3394	2895	2519	1862	1327	980		4290	3568	3048	2656	2104	1672	1244		4507	3756	3214	2804	2225	1836	1508
13																							
13.0	3570	2992	2570	2249	1532	1087	798		3766	3162	2720	2383	1901	1368	1013		3978	3346	2882	2528	2020	1647	1227
14.0	3951	3296	2821	2461	1697	1206	886		4149	3467	2972	2596	2063	1522	1128		4363	3652	3135	2742	2183	1805	1370
15.0	4359	3617	3084	2683	1863	1324	974		4559	3789	3236	2818	2231	1675	1243		4774	3976	3400	2965	2352	1939	1514
14																							
14.0	4192	3495	2990	2518	1697	1202	881		4388	3664	3140	2742	2135	1524	1127		4600	3848	3302	2886	2297	1847	1374
15.0	4630	3840	3273	2760	1862	1320	968		4827	4010	3423	2981	2347	1676	1241		5041	4195	3586	3126	2478	2037	1517
15																							
15.0	4901	4063	3455	2762	1859	1314	961		5096	4232	3611	3143	2350	1675	1237		5308	4415	3773	3288	2604	2042	1518

3 Bars per Beam

SPAN	4	5	6	7	8	9	10		4	5	6	7	8	9	10		4	5	6	7	8	9	10
E H	NO. 3								NO. 4								NO. 5						
7																							
7.0	1275	801	543	388	287	218	168		1700	1288	959	694	521	403	318		1911	1453	1170	977	767	597	475
8.0	1531	962	653	467	346	263	204		2045	1529	1165	843	634	491	388		2259	1697	1355	1126	945	737	588
9.0	1327	829	555	396	291	218	166		2431	1791	1371	993	747	579	459		2647	1961	1554	1283	1091	877	700
10.0	1517	949	641	455	334	251	192		2865	2078	1577	1142	860	667	529		3085	2250	1766	1451	1228	1017	812
11.0	1708	1069	722	513	377	284	217		3359	2393	1782	1292	974	755	599		3581	2567	1995	1628	1372	1156	924
12.0	1898	1189	803	571	420	317	243		3924	2739	1988	1441	1087	843	669		4147	2915	2242	1817	1525	1296	1036
13.0	2089	1309	885	629	463	350	268		4577	3123	2194	1591	1200	931	740		4802	3301	2509	2019	1685	1436	1148
14.0	2279	1428	966	687	506	382	294		5341	3493	2400	1741	1313	1020	810		5565	3729	2798	2234	1855	1576	1261
15.0	2470	1548	1047	745	550	415	319		5976	3792	2605	1890	1426	1108	880		6469	4209	3113	2464	2035	1716	1373
e																							
8.0	1136	707	474	334	243	180	135		2276	1699	1172	846	635	490	386		2486	1865	1488	1235	957	745	593
9.0	1326	826	555	391	285	212	160		2715	1998	1377	995	747	577	456		2928	2166	1714	1415	1135	884	704
10.0	1516	945	635	448	327	244	184		3210	2308	1582	1144	860	665	525		3425	2495	1956	1605	1313	1023	815
11.0	1705	1064	716	506	369	276	209		3772	2606	1787	1293	972	752	595		3989	2855	2217	1808	1490	1162	927
12.0	1895	1183	796	563	412	308	234		4416	2904	1992	1441	1084	839	664		4634	3252	2498	2023	1668	1301	1038
13.0	2085	1302	877	620	454	340	258		5054	3202	2197	1590	1196	926	733		5379	3690	2802	2252	1846	1440	1149
14.0	2274	1421	957	678	496	372	283		4119	2601	1777	1280	957	736	578		6249	4179	3131	2498	2024	1579	1260
15.0	2464	1540	1038	735	538	404	307		4469	2823	1929	1390	1040	800	628		7279	4725	3490	2760	2202	1718	1372
s																							
9.0	1324	822	549	385	278	205	153		2999	2018	1380	995	746	574	452		3209	2371	1875	1513	1142	887	705
10.0	1512	940	629	442	320	236	177		3555	2315	1584	1143	857	661	520		3766	2739	2146	1746	1319	1025	816
11.0	1701	1058	709	498	361	268	200		4130	2612	1788	1291	968	747	589		4398	3143	2439	1979	1495	1164	926
12.0	1890	1176	788	554	403	299	224		3426	2159	1471	1056	787	602	470		5122	3588	2754	2213	1672	1302	1037
13.0	2079	1294	868	611	444	330	248		3775	2380	1622	1165	868	665	519		5957	4080	3095	2446	1849	1440	1147
14.0	2268	1412	948	667	485	361	272		4125	2601	1773	1274	950	728	569		6933	4628	3465	2680	2026	1578	1258
15.0	2457	1530	1027	724	527	392	295		4474	2822	1924	1383	1031	791	618		8088	5241	3867	2913	2203	1716	1368
10																							
10.0	1508	934	622	434	312	229	169		3672	2319	1584	1141	853	656	515		4107	2984	2336	1752	1322	1026	815
11.0	1696	1051	701	490	353	259	192		3081	1938	1317	942	699	532	413		4807	3431	2660	1985	1498	1163	924
12.0	1884	1169	780	546	393	289	215		3430	2158	1467	1050	780	594	462		5609	3925	3010	2218	1674	1301	1034
13.0	2072	1286	859	601	434	319	237		3778	2378	1617	1158	861	656	510		6535	4470	3375	2450	1850	1438	1143
14.0	2260	1403	937	657	475	350	260		4127	2598	1767	1266	941	718	559		7617	5077	3695	2663	2026	1575	1253
15.0	2448	1520	1016	712	515	380	283		4476	2818	1918	1375	1022	780	608		8898	5757	4015	2915	2202	1713	1363
11																							
11.0	1690	1044	693	482	344	250	183		3083	1936	1312	937	693	525	406		5216	3720	2743	1988	1498	1161	921
12.0	1877	1161	771	536	384	280	205		3431	2155	1462	1044	772	586	453		6096	4261	3062	2220	1673	1298	1030
13.0	2065	1277	845	591	424	309	227		3779	2374	1611	1151	852	648	501		7113	4860	3381	2451	1848	1434	1138
14.0	2252	1393	927	646	463	338	249		4127	2594	1761	1258	932	709	549		8301	5386	3700	2683	2023	1571	1247
15.0	2439	1510	1005	701	503	368	271		4475	2813	1910	1366	1012	770	597		9220	5849	4199	2915	2198	1707	1356

Table 135-19. continued.

3 Bars per Beam

SPAN E H S	3 Bars per Beam																																															
	7	8	9	10	12	14	16	7	8	9	10	12	14	16	7	8	9	10	12	14	16	7	8	9	10	12	14	16	7	8	9	10	12	14	16													
	NO. 6																NO. 7																NO. 8															
9.0	1579	1345	1118	892	598	421	268	1751	1495	1302	1151	780	519	326	1959	1675	1460	1289	956	602	381	2171	1850	1609	1421	1149	830	501	2396	2033	1763	1554	1252	976	727													
10.0	1787	1517	1315	1052	707	499	364	1962	1668	1448	1278	931	664	478	2171	1850	1609	1421	1149	830	501	2396	2033	1763	1554	1252	976	727	2635	2227	1924	1692	1358	1122	837													
11.0	2009	1697	1467	1212	816	577	422	2185	1850	1601	1410	1082	773	571	2396	2033	1763	1554	1252	976	727	2635	2227	1924	1692	1358	1122	837	2890	2430	2054	1836	1468	1218	947													
12.0	2244	1888	1626	1372	925	655	479	2422	2042	1762	1547	1233	881	653	2635	2227	1924	1692	1358	1122	837	2890	2430	2054	1836	1468	1218	947	3161	2645	2271	1986	1582	1309	1057													
13.0	2494	2089	1793	1532	1033	732	537	2674	2244	1929	1689	1347	990	735	2890	2430	2054	1836	1468	1218	947	3161	2645	2271	1986	1582	1309	1057	3450	2872	2456	2142	1700	1402	1167													
14.0	2762	2301	1967	1692	1142	810	595	2943	2457	2105	1838	1460	1099	816	3161	2645	2271	1986	1582	1309	1057	3450	2872	2456	2142	1700	1402	1167	3723	3097	2647	2307	1828	1507	1173													
15.0	3047	2525	2151	1852	1251	888	653	3230	2683	2290	1994	1577	1208	858	3450	2872	2456	2142	1700	1402	1167	3723	3097	2647	2307	1828	1507	1173	4000	3366	2916	2554	2154	1784	1454													
10	10.0	1928	1636	1327	1059	709	498	2101	1786	1550	1367	942	669	492	2309	1966	1709	1509	1182	846	582	2558	2169	1880	1656	1333	991	736	2822	2383	2058	1809	1450	1136	845													
11.0	2173	1836	1526	1218	817	575	418	2348	1987	1719	1512	1092	777	573	2558	2169	1880	1656	1333	991	736	2822	2383	2058	1809	1450	1136	845	3103	2608	2245	1968	1572	1281	954													
12.0	2434	2047	1724	1377	925	652	475	2610	2199	1896	1664	1242	885	654	2822	2383	2058	1809	1450	1136	845	3103	2608	2245	1968	1572	1281	954	3403	2846	2441	2134	1698	1404	1063													
13.0	2712	2269	1923	1536	1032	729	532	2889	2423	2082	1822	1393	993	734	3187	2659	2277	1987	1543	1102	815	3403	2846	2441	2134	1698	1404	1063	3723	3097	2647	2307	1828	1507	1173													
14.0	3008	2504	2121	1695	1140	806	589	3187	2659	2277	1987	1543	1102	815	3505	2909	2481	2159	1693	1210	896	3723	3097	2647	2307	1828	1507	1173	4000	3366	2916	2554	2154	1784	1454													
15.0	3324	2753	2320	1854	1248	883	646	3505	2909	2481	2159	1693	1210	896	3723	3097	2647	2307	1828	1507	1173	4000	3366	2916	2554	2154	1784	1454	4286	3646	3196	2834	2434	2034	1634													
12	12.0	2814	2224	1731	1379	919	643	2987	2514	2166	1855	1251	886	649	3196	2695	2326	2042	1613	1152	853	3531	2963	2548	2232	1780	1295	960	3888	3247	2782	2430	1930	1439	1068													
13.0	3146	2476	1928	1536	1026	718	516	3320	2781	2388	2074	1399	992	728	3531	2963	2548	2232	1780	1295	960	3888	3247	2782	2430	1930	1439	1068	4055	3361	2864	2491	1696	1205	886													
14.0	3500	2727	2125	1693	1132	793	573	3675	3063	2620	2285	1548	1099	807	4055	3361	2864	2491	1696	1205	886	4269	3546	3027	2636	2086	1582	1175	4542	3771	3218	2801	2215	1583	1173													
15.0	3878	2979	2321	1851	1238	868	629	4055	3361	2864	2491	1696	1205	886	4269	3546	3027	2636	2086	1582	1175	4542	3771	3218	2801	2215	1583	1173	4542	3771	3218	2801	2215	1583	1173													
13	13.0	3281	2478	1927	1533	1020	711	3536	2960	2541	2079	1399	989	723	3744	3141	2700	2364	1820	1298	960	4130	3447	2953	2578	2018	1441	1066	4330	3588	3056	2514	1694	1200	880													
14.0	3612	2729	2123	1650	1126	786	565	3919	3265	2792	2296	1547	1095	802	4130	3447	2953	2578	2018	1441	1066	4330	3588	3056	2514	1694	1200	880	4330	3588	3056	2514	1694	1200	880													
15.0	3943	2980	2319	1847	1231	860	619	4330	3588	3056	2514	1694	1200	880	4542	3771	3218	2801	2215	1583	1173	4542	3771	3218	2801	2215	1583	1173	4542	3771	3218	2801	2215	1583	1173													
	NO. 9																NO. 10																NO. 11															
11	11.0	2952	2506	2173	1916	1544	1216	3255	2768	2404	2113	1695	1409	1083	3780	3176	2734	2397	1916	1590	1354	4197	3545	3045	2697	2161	1789	1522	4534	3813	3266	2883	2308	1918	1635													
12.0	3243	2742	2371	2085	1674	1353	1046	3550	3006	2604	2293	1846	1535	1263	3780	3176	2734	2397	1916	1590	1354	4197	3545	3045	2697	2161	1789	1522	4534	3813	3266	2883	2308	1918	1635													
13.0	3554	2990	2577	2261	1808	1501	1185	3863	3257	2812	2470	1981	1647	1405	4197	3545	3045	2697	2161	1789	1522	4534	3813	3266	2883	2308	1918	1635	4893	4095	3516	3077	2454	2034	1731													
14.0	3884	3252	2793	2444	1947	1612	1325	4197	3522	3030	2655	2121	1759	1497	4534	3813	3266	2883	2308	1918	1635	4893	4095	3516	3077	2454	2034	1731	4893	4095	3516	3077	2454	2034	1731													
15.0	4237	3530	3020	2635	2091	1726	1463	4553	3802	3259	2848	2266	1874	1552	4553	3802	3259	2848	2266	1874	1552	4553	3802	3259	2848	2266	1874	1552	4553	3802	3259	2848	2266	1874	1552													
12	12.0	3429	2896	2503	2201	1766	1417	3733	3160	2735	2408	1937	1613	1286	4062	3444	2983	2615	2091	1735	1478	4405	3719	3213	2825	2269	1889	1612	4770	4009	3452	3028	2422	2011	1713													
13.0	3765	3166	2727	2391	1912	1585	1195	4073	3432	2961	2600	2084	1731	1464	4405	3719	3213	2825	2269	1889	1612	4770	4009	3452	3028	2422	2011	1713	4770	4009	3452	3028	2422	2011	1713													
14.0	4124	3451	2962	2591	2063	1706	1332	4435	3720	3198	2801	2236	1853	1576	4770	4009	3452	3028	2422	2011	1713	4770	4009	3452	3028	2422	2011	1713	4770	4009	3452	3028	2422	2011	1713													
15.0	4508	3753	3209	2798	2219	1830	1472	4822	4023	3446	3010	2393	1978	1679	4822	4023	3446	3010	2393	1978	1679	4822	4023	3446	3010	2393	1978	1679	4822	4023	3446	3010	2393	1978	1679													
13	13.0	3977	3343	2878	2522	2015	1613	4283	3607	3110	2730	2186	1815	1481	4613	3892	3361	2954	2370	1972	1682	5007	4205	3619	3172	2536	2104	1792	5427	4535	3889	3400	2707	2240	1904													
14.0	4365	3650	3131	2737	2178	1796	1338	4674	3917	3366	2947	2350	1946	1655	5007	4205	3619	3172	2536	2104	1792	5427	4535	3889	3400	2707	2240	1904	5427	4535	3889	3400	2707	2240	1904													
15.0	4779	3976	3358	2962	2347	1935	1476	5090	4245	3634	3172	2520	2082	1766	5427	4535	3889	3400	2707	2240	1904	5427	4535	3889	3400	2707	2240	1904	5427	4535	3889	3400	2707	2240	1904													
14	14.0	4605	3849	3301	2884	2293	1804	4912	4115	3534	3092	2465	2040	1671	5244	4401	3786	3317	2650	2197	1870	5694	4755	4075	3561	2833	2343	1990	5961	4974	4262	3722	2960	2446	2076													
15.0	5049	4199	3587	3125	2475	1986	1478	5359	4466	3822	3335	2647	2185	1848	5694	4755	4075	3561	2833	2343	1990	5961	4974	4262	3722	2960	2446	2076	5961	4974	4262	3722	2960	2446	2076													
15	15.0	5320	4422	3776	3289	2603	1990	5628	4687	4009	3497	2775	2289	1856	5961	4974	4262	3722	2960	2446	2076	5961	4974	4262	3722	2960	2446	2076	5961																			

Table 135-19. continued.

4 Bars per Beam

SPAN E H	7	8	9	10	12	14	16	7	8	9	10	12	14	16	7	8	9	10	12	14	16	
	NO. 6							NO. 7							NO. 8							
11	11.0	2513	2125	1837	1608	1085	769	565	2750	2330	2018	1777	1429	1022	758	3034	2576	2234	1970	1588	1281	956
	12.0	2802	2358	2032	1782	1231	874	642	3041	2565	2214	1945	1558	1169	868	3327	2813	2432	2140	1719	1430	1104
	13.0	3109	2604	2236	1956	1376	979	720	3350	2813	2420	2120	1692	1315	978	3640	3063	2640	2316	1854	1539	1251
	14.0	3436	2864	2450	2137	1522	1083	798	3680	3074	2635	2302	1830	1461	1087	3972	3327	2857	2500	1993	1650	1398
	15.0	3786	3139	2675	2327	1668	1188	876	4032	3351	2861	2493	1974	1607	1197	4327	3606	3085	2692	2137	1765	1497
12	12.0	2992	2517	2168	1830	1233	873	639	3229	2722	2349	2062	1645	1175	871	3514	2969	2566	2256	1811	1496	1116
	13.0	3326	2785	2390	2043	1378	977	716	3565	2992	2573	2253	1797	1321	980	3853	3241	2792	2448	1958	1624	1263
	14.0	3682	3068	2623	2257	1523	1080	793	3924	3276	2807	2451	1947	1466	1089	4214	3527	3028	2648	2109	1745	1409
	15.0	4063	3367	2868	2470	1668	1184	870	4307	3577	3053	2658	2103	1611	1197	4600	3830	3275	2857	2266	1870	1556
13	13.0	3543	2965	2544	2047	1377	973	711	3781	3171	2725	2386	1855	1324	980	4067	3418	2943	2580	2062	1704	1271
	14.0	3928	3271	2797	2260	1521	1076	787	4168	3478	2979	2600	2055	1469	1088	4457	3728	3198	2796	2225	1840	1416
	15.0	4340	3595	3061	2472	1666	1179	863	4582	3803	3245	2824	2233	1613	1156	4873	4055	3466	3021	2395	1975	1562
14	14.0	4175	3475	2831	2261	1519	1071	780	4412	3680	3151	2749	2060	1469	1085	4699	3928	3369	2944	2342	1907	1421
	15.0	4617	3822	3095	2473	1662	1173	856	4857	4029	3436	2990	2260	1612	1152	5146	4279	3656	3186	2524	2080	1566
15	15.0	4894	3970	3096	2471	1657	1166	847	5132	4256	3628	3156	2262	1610	1188	5419	4504	3846	3351	2653	2106	1567
	NO. 9							NO. 10							NO. 11							
13	13.0	4385	3693	3185	2796	2239	1660	1557	4801	4052	3501	3078	2471	2057	1756							
	14.0	4778	4005	3442	3014	2404	1992	1694	5198	4367	3760	3297	2638	2190	1866							
	15.0	5198	4335	3712	3241	2575	2127	1805	5622	4700	4033	3526	2810	2326	1978							
14	14.0	5019	4204	3611	3161	2520	2086	1759	5437	4565	3928	3443	2752	2283	1944	5887	4953	4270	3748	3002	2496	2129
	15.0	5469	4558	3901	3404	2703	2232	1893	5891	4922	4220	3689	2937	2430	2065	6347	5314	4564	3996	3189	2643	2250
15	15.0	5740	4781	4090	3568	2831	2336	1955	6160	5143	4408	3851	3064	2534	2152	6613	5534	4751	4157	3315	2746	2337

SLATS

1 Bar per Slat

SPAN	4	5	6	7	8	9	10	4	5	6	7	8	9	10	4	5	6	7	8	9	10	
E H	NO. 3							NO. 4							NO. 5							
4	4.0	173	106	69	47	33	23	16	295	180	120	87	63	47	35	395	208	126	84	62	51	45
	4.5	215	132	87	60	42	30	21	373	233	157	111	75	53	40	529	334	196	123	82	57	41
	5.0	188	114	74	50	34	23	15	450	282	190	135	99	73	52	603	411	280	201	132	89	62
	5.5	220	134	87	59	40	28	19	528	331	224	159	118	89	68	680	488	333	235	177	121	85
	6.0	251	153	100	68	47	33	22	606	380	258	184	136	103	79	761	565	386	278	208	160	118
	6.5	282	172	112	77	53	37	26	684	425	291	208	154	117	90	847	642	439	316	237	182	143
	7.0	313	191	125	86	60	42	29	761	478	325	232	172	131	101	937	709	492	355	266	205	161
	7.5	344	211	138	95	66	47	33	839	527	358	256	190	145	112	1031	776	545	393	295	228	179
	8.0	375	230	151	104	73	52	36	917	577	392	280	208	159	123	1132	846	598	432	324	250	197
5	5.0	186	111	71	46	30	19	11	456	284	190	134	97	72	54	670	421	286	204	138	95	68
	5.5	217	130	83	55	36	24	14	533	332	224	158	115	86	65	791	498	338	242	180	137	98
	6.0	248	149	95	63	42	28	18	610	381	257	182	133	100	76	899	574	391	280	208	159	124
	6.5	278	168	108	72	48	32	21	688	430	290	205	151	113	86	1005	651	443	318	237	181	141
	7.0	309	187	120	80	54	37	24	765	479	323	229	168	127	97	1117	728	496	356	266	203	159
	7.5	339	205	133	89	60	41	27	823	527	359	262	191	145	112	1234	804	549	394	294	226	177
	8.0	370	224	145	97	66	45	30	901	577	392	280	208	159	123	1132	846	598	432	324	250	197
6	6.0	244	145	91	59	37	23	13	451	277	183	126	89	64	46	923	579	393	280	207	157	121
	6.5	274	163	103	67	43	27	15	508	313	207	143	101	73	53	1043	655	445	318	235	175	138
	7.0	304	182	115	75	49	31	18	565	348	231	160	114	82	60	1164	732	497	355	263	201	155
	7.5	334	200	127	83	54	35	21	622	384	255	177	126	91	67	1284	808	545	393	292	222	173
	8.0	365	218	139	91	60	39	23	679	419	275	194	138	101	74	1405	884	601	431	320	244	190
7	7.0	299	176	109	69	43	25	12	562	345	226	155	109	77	54	1169	733	496	353	260	197	151
	7.5	329	194	121	77	48	28	14	619	380	250	171	121	86	61	1289	808	547	390	288	218	168
	8.0	359	212	132	84	53	32	17	675	415	273	188	132	94	67	1404	881	601	431	320	244	190
5		6	7	8	9	10	12	14	6	7	8	9	10	12	14	6	7	8	9	10	12	14
		NO. 6							NO. 7							NO. 8						
	5.0	292	186	127	92	70	48	38	312	198	133	93	69	43	31	334	210	135	96	69	39	25
	5.5	379	264	176	123	88	50	32	466	292	193	133	94	50	29	515	321	211	145	102	53	28
	6.0	454	327	244	172	123	66	37	574	415	275	192	136	72	39	643	470	310	212	150	79	43
	6.5	530	382	285	220	161	87	49	666	491	369	268	190	102	56	742	555	433	298	211	113	63
	7.0	605	436	327	252	198	117	66	726	566	426	331	252	137	77	802	672	525	400	285	155	88
	7.5	681	491	369	284	224	146	86	788	642	484	375	298	178	103	865	723	602	468	371	203	118
	8.0	756	546	410	317	250	163	109	852	709	541	420	334	221	131	930	775	663	528	421	262	154
6	6.0	462	332	247	187	134	74	45	595	429	306	211	150	80	45	722	507	335	230	163	86	47
	6.5	538	386	288	220	172	96	55	658	504	378	287	204	109	61	820	622	468	322	229	122	68
	7.0	613	441	329	252	197	126	72	802	579	435	336	265	147	83	893	722	544	422	307	166	94
	7.5	688	495	370	284	223	143	93	852	654	492	380	301	191	110	967	808	620	462	383	221	127
	8.0	763	549	411	316	248	159	106	969	730	549	425	336	221	139	1044	870	696	541	430	280	163
7	7.0	617	442	328	250	195	122	77	814	587	439	338	266	158	89	983	739	556	430	330	179	101
	7.5	691	496	369	282	220	139	90	917	661	496	382	301	195	116	1070	835	632	489	388	233	134
	8.0	766	550	410	313	245	155	101	1020	736	552	426	336	218	147	1159	938	707	548	435	287	172

Welded Wire Fabric

Selection tables in this section are provided only for manure tank walls and lids. Follow the Procedure Summary outlined previously, but select steel areas for walls and lids from Tables 135-26 to 135-28.

Use flat sheets of welded wire fabric, not rolls. Welded wire fabric is made from cold drawn steel with a yield

point of 60,000 psi. All other stresses are the same as those given on Table 135-1.

The development of at least 2 cross wires 2" or more beyond the point of critical section develops the full yield strength; embedment of 1 wire 2" or more develops $\frac{1}{2}$ the yield strength.

Table 135-20. Minimum welded wire fabric steel in walls, sq in./ft.

Temperature and shrinkage steel:

Area = 0.002bt horizontal

Area = 0.0012bt vertical

Wall Thickness, in.	4"	5"	6"	7"
Vert. A_s /ft	0.0576	0.0720	0.0864	0.1008
Horiz. A_s /ft	0.0960	0.1200	0.1440	0.1680

Wall Thickness, in.	8"	9"	10"	11"	12"
Vert. A_s /ft	0.1152	0.1296	0.1440	0.1584	0.1728
Horiz. A_s /ft	0.1920	0.2160	0.2400	0.2640	0.2880

Table 135-21. Minimum welded wire fabric steel in slabs, sq in./ft.

Temperature and shrinkage steel:

Area = 0.0018bt in both directions

Slab Thickness, in.	4"	5"	6"	7"
A_s /ft	0.0864	0.1080	0.1296	0.1512

Slab Thickness, in.	8"	9"	10"	11"	12"
A_s /ft	0.1728	0.1944	0.2160	0.2376	0.2592

Table 135-22. Wire size comparison.

W & D Size Number		Area (sq in.)	Nominal Diameter (in.)	AMERICAN STEEL & WIRE Gage Number
Smooth	Deformed			
W14	D14	0.122	0.394	4/0
W12	D12	.120	.390	
W11	D11	.110	.374	3/0
W10.5		.105	.366	
		.103	.3625	
W10	D10	0.100	0.356	2/0
W9.5		.095	.348	
W9	D9	.090	.338	
		.086	.331	
W8.5		.085	.329	1/0
W8	D8	0.080	0.319	
W7.5		.075	.309	
		.074	.3065	
W7	D7	.070	.298	1
W6.5		.065	.288	
		0.063	0.283	2
S6	D6	.060	.276	
W5.5		.055	.264	3
		.054	.2625	
W5	D5	.050	.252	4
		0.047	0.244	
W4.5		.045	.240	5
W4	D4	.040	.225	
W3.5		.035	.211	6
		.034	.207	
W3		0.030	0.195	7
W2.9		.029	.192	
W2.5		.025	.177	8
W2.1		.021	.162	
W2		.020	.159	9
		0.017	0.148	
W1.5		.015	.138	10
W1.4		.014	.135	

NOTE: "W" or "D" wire size = wire area in hundredths of a square inch; e.g. W4.5 has a cross-sectional area = 0.045 sq.in.

Table 135-23. Sectional areas of welded wire fabric.
(Area, sq in./ft of width for various spacings)

Wire Size Number Smooth Deformed	Nominal Diameter in.	Nominal Weight lbs/lin ft	Sectional Steel Area Wire Spacing, o.c.			
			4"	6"	8"	10"
W12	D12	0.390	.408	.36	.24	.18
W11	D11	0.374	.374	.33	.22	.165
W10.5		0.366	.357	.315	.21	.157
W10	D10	0.356	.340	.30	.20	.15
W9.5		0.348	.323	.285	.19	.142
W9	D9	0.338	.306	.27	.18	.135
W8.5		0.329	.289	.255	.17	.127
W8	D8	0.319	.272	.24	.16	.12
W7.5		0.309	.255	.225	.15	.112
W7	D7	0.298	.238	.21	.14	.105
W6.5		0.288	.221	.195	.13	.097
W6	D6	0.276	.204	.18	.12	.09
W5.5		0.264	.187	.165	.11	.082
W5	D5	0.252	.170	.15	.10	.075
W4.5		0.240	.153	.135	.09	.067
W4	D4	0.225	.136	.12	.08	.06
W3.5		0.211	.119	.105	.07	.052
W3		0.195	.102	.09	.06	.045
W2.9		0.192	.098	.087	.058	.043
W2.5		0.178	.085	.075	.05	.037
W2.1		0.162	.070	.063	.042	.031
W2		0.159	.068	.06	.04	.03
W1.5		0.138	.051	.045	.03	.022
W1.4		0.135	.049	.042	.028	.021

Table 135-24. Typical stock items.*

Style Designation by by		Spacing** in.	Diameter** in.	Sectional Area** sq in./ft	Weight lbs per 100 sq/ft
Wire Gage	W-or-D-Number				
6x6-10x10	6x6-W1.4xW1.4	6	.135	.029	21
6x6-8x8	6x6-W2.1xW2.1	6	.162	.041	30
6x6-6x6	6x6-W2.9xW2.9	6	.192	.058	42
6x6-4x4	6x6-W4xW4	6	.225	.080	58
4x4-10x10	4x4-W1.4xW1.4	4	.135	.043	31
4x4-6x6	4x4-W2.9xW2.9	4	.192	.087	62
4x4-4x4	4x4-W4xW4	4	.225	.120	85

*These items may be carried in sheets by various manufacturers in certain parts of the U.S. and Canada.

**The spacing, diameter, and sectional area of the welded wire fabric are the same in both the longitudinal and transverse directions.

Table 135-25. Sectional areas of steel reinforcing.
Both bars and fabric are Grade 60
(60,000 psi) steel.

Wire Size Number (W or D Numbers) Spacing; in., o.c.		Steel Area in. ² /ft.	Bar Spacing, in., o.c. Rebar Size Number		
4"	6"	12"	#3	#4	#5
	3.5	7	0.07 in. ² /ft.		
	4	8	0.08		
3	4.5	9	0.09		
	5	10	0.10		
	5.5	11	0.11		
4	6	12	0.12		
	6.5		0.13		
	7		0.14		
5	7.5		0.15		
	8		0.16		
	8.5		0.17		
6	9		0.18		
	9.5		0.19		
	10		0.20		
*7	10.5		0.21		
	11		0.22		
			0.23		
8	12		0.24		
			0.25		
			0.26		
9			0.27		
			0.28		
			0.29		
10			0.30		
	31		0.31		
			0.32		
11			0.33		
			0.34		
			0.35		
12			0.36		

NOTE: Table 7 is based on equal allowable steel stresses. If comparing different grades of steel, the designer should compensate accordingly. For instance, f_y of Grade 40 or 50 steel is 40,000 psi whereas welded fabric and Grade 60 steel have a value of 60,000 psi for f_y .

*Six steel combinations equal 0.21 in.²/ft: W7 or D7 wire 4" o.c., W10.5 or D10.5 wire 6" o.c., #4 bars 11½" o.c., or #5 bars 17½" o.c.

Table 135-26. Reinforced concrete tank walls; vertical reinforced design; in.²/ft steel required.

Tabulated reinforcing is vertical; minimum reinforcing (Table 135-4) is horizontal. A 100 pcf surcharge on the hydrastatic wall load is recommended when installing or moving heavy equipment within 5' of the tank walls, see bottom of Table 135-26.

Wall Thickness	Load, pcf	Hydrastatic Load						
		6'	7'	8'	9'	10'	12'	14'
6"	15	0.0864	0.0864	0.0864	0.0864	0.0864	0.1473	0.2383
	30	0.0864	0.0864	0.0864	0.1237	0.1714	—	—
	60	0.0864	0.1163	0.1756	0.2540	—	—	—
7"	15	0.1008	0.1008	0.1008	0.1008	0.1008	0.1188	0.1909
	30	0.1008	0.1008	0.1008	0.1008	0.1379	0.2424	—
	60	0.1008	0.1008	0.1413	0.2132	0.2824	—	—
8"	15	0.1152	0.1152	0.1152	0.1152	0.1152	0.1152	0.1595
	30	0.1152	0.1152	0.1152	0.1152	0.1156	0.2021	0.3264
	60	0.1152	0.1152	0.1184	0.1698	0.2350	0.4162	—
9"	15	0.1296	0.1296	0.1296	0.1296	0.1296	0.1296	0.1372
	30	0.1296	0.1296	0.1296	0.1296	0.1296	0.1735	0.2789
	60	0.1296	0.1296	0.1296	0.1459	0.2015	0.3545	0.5782
10"	15	0.1440	0.1440	0.1440	0.1440	0.1440	0.1440	0.1440
	30	0.1440	0.1440	0.1440	0.1440	0.1440	0.1521	0.2438
	60	0.1440	0.1440	0.1440	0.1440	0.1765	0.3092	0.5009
11"	15	0.1584	0.1584	0.1584	0.1584	0.1584	0.1584	0.1584
	30	0.1584	0.1584	0.1584	0.1584	0.1584	0.1584	0.2167
	60	0.1584	0.1584	0.1584	0.1584	0.1584	0.2744	0.4426
12"	15	0.1728	0.1728	0.1728	0.1728	0.1728	0.1728	0.1728
	30	0.1728	0.1728	0.1728	0.1728	0.1728	0.1728	0.1952
	60	0.1728	0.1728	0.1728	0.1728	0.1728	0.2468	0.3969

Hydrastatic Load + 100 pcf surcharge for Vehicle Load								
Wall Thickness	Load, pcf	6'	7'	8'	9'	10'	12'	14'
6"	15	0.0864	0.0864	0.1131	0.1511	0.1967	—	—
	30	0.0864	0.1113	0.1575	0.2157	0.2876	—	—
	60	0.1121	0.1712	0.2493	0.3509	—	—	—
7"	15	0.1008	0.1008	0.1008	0.1218	0.1581	0.2512	—
	30	0.1008	0.1008	0.1269	0.1730	0.2295	0.3800	—
	60	0.1008	0.1378	0.1995	0.2786	0.3783	—	—
8"	15	0.1152	0.1152	0.1152	0.1152	0.1323	0.2571	0.3747
	30	0.1152	0.1152	0.1152	0.1448	0.1915	0.3934	—
	60	0.1152	0.1155	0.1667	0.2318	0.3131	—	—
9"	15	0.1296	0.1296	0.1296	0.1296	0.1296	0.1797	0.2668
	30	0.1296	0.1296	0.1296	0.1296	0.1645	0.2689	0.4127
	60	0.1296	0.1296	0.1433	0.1988	0.2677	0.4539	—
10"	15	0.1440	0.1440	0.1440	0.1440	0.1440	0.1575	0.2333
	30	0.1440	0.1440	0.1440	0.1440	0.1440	0.2351	0.3593
	60	0.1440	0.1440	0.1440	0.1742	0.2341	0.3947	0.6229
11"	15	0.1584	0.1584	0.1584	0.1584	0.1584	0.1584	0.2074
	30	0.1584	0.1584	0.1584	0.1584	0.1584	0.2090	0.3186
	60	0.1584	0.1584	0.1584	0.1584	0.2082	0.3497	0.5487
12"	15	0.1728	0.1728	0.1728	0.1728	0.1728	0.1728	0.1868
	30	0.1728	0.1728	0.1728	0.1728	0.1728	0.1882	0.2863
	60	0.1728	0.1728	0.1728	0.1728	0.1875	0.3141	0.4910

All 6' deep tanks require only minimum temperature and shrinkage reinforcement.

Design Example

Design an indoor, under-floor manure tank for a tractor-scraped free-stall dairy barn.

Walls

Determine the soil characteristics and choose the design load from Table 135.5, for this example use 60 psf/ft. Determine tank depth from manure storage requirements, use 8'. Select vertical steel from Table 135.26: 8" wall, no surcharge, 0.1184 in.²/ft of wall length. Select horizontal steel (for temperature and shrinkage) from Table 135.20: 0.1920 in.²/ft of wall height.

Lids

Determine the span of the slab, usually not over 12'; use 10'. The manure tank lid must support a tractor or manure wagon, or livestock traffic. Select principal reinforcing steel from Table 135.28 for the tractor load, or from Table 135.27 for the animal traffic load, whichever is larger: 8" lid thickness, Table 135.28 requires 0.2941 in.²/ft, Table 135.27 requires 0.1759 in.²/ft, use 0.2941 in.²/ft. Select temperature and shrinkage steel for the chosen lid thickness from Table 135.21: 8" lid requires 0.1728 in.²/ft. See MWPS Plan No. 74303 for reinforcing of scrape or agitation openings and other details.

Obtaining Required Steel Areas

Table 135.24 gives some typical stock sizes of welded wire fabric and their steel areas per foot. Use Tables 135.22 and 135.23 to specify a fabric to be specially welded. Use Table 135.25 to combine welded wire fabric and Grade 60 reinforcing bars.

Wall Example

Vertical steel area required = 0.1184 in.²/ft = 4x4—W4xW4 (Table 135.24); horizontal steel area required = 0.1920 in.²/ft = 4x4—W6.5xW6.5.

Select: (a) Fabric with W4 wires vertical and W6.5 wires horizontal, 4" o.c., or (b) 4x4—W6.5xW6.5 fabric (more vertical steel than required), or (c) 4x4—W4xW4 Fabric plus #3, grade 60, bars 16½" o.c. horizontally (.1920 horiz—.120 from fabric = 0.072 in.² needed; select #3, 16½" o.c. from Table 135.25).

Lid Example

Principle steel area = 0.2941 in.²/ft across span; temperature steel area = 0.1728.

Select: 6x6—W4xW4 (Table 135.24), area = 0.080 in.²/ft. both ways. Add Grade 60 bars as needed (Table 135.25): 0.2941—0.080 = 0.2131 in.², #4 bars 11" o.c. across span; 0.1728—0.080 = 0.0928 in.², #3 bars 13" o.c. for temperature and shrinkage.

Tank Lids

steel cover = $1\frac{1}{2}$ " for #5 or smaller.
= 2" for #6 or larger.

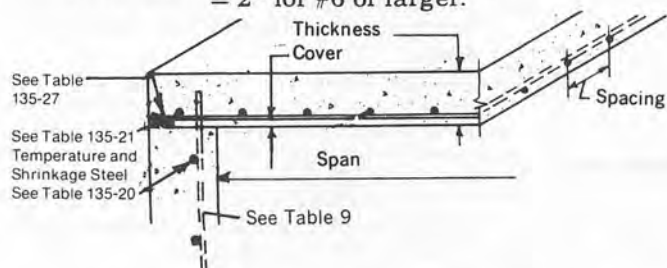


Table 135-27. Reinforced concrete tank lids for NO vehicle traffic; one-way slab design adequate for load listed plus dead weight of slab; sectional area of steel required,

Lid Thickness	6'	7'	Lid Span*					Lid Thickness	12'	Lid Span**			
			8'	9'	10'	12'	14'			14'	16'		
PSF													
4"	40	0.0864	0.0864	0.1068	0.1366	0.1709	-	-	8"	40	0.1728	0.1816	0.2391
	50	"	0.0913	0.1206	0.1545	0.1936	-	-		50	"	0.1969	0.2594
	60	"	0.1017	0.1345	0.1726	-	-	-		60	"	0.2122	0.2797
	70	"	0.1122	0.1485	0.1910	-	-	-		70	"	0.2276	0.3002
	80	0.0891	0.1228	0.1627	0.2097	-	-	-		80	0.1770	0.2431	0.3209
	90	0.0967	0.1334	0.1771	-	-	-	-		90	0.1882	0.2586	0.3416
	100	0.1044	0.1442	0.1917	-	-	-	-		100	0.1994	0.2742	0.3625
	110	0.1121	0.1550	0.2064	-	-	-	-		110	0.2106	0.2898	-
150	0.1434	0.1993	-	-	-	-	-	150	0.2560	0.3531	-		
5"	40	0.1080	0.1080	0.1080	0.1080	0.1318	0.1929	-	9"	40	0.1944	0.1944	0.2227
	50	"	"	"	"	0.1468	0.2152	-		50	"	"	0.2400
	60	"	"	"	0.1301	0.1619	0.2378	-		60	"	0.1956	0.2574
	70	"	"	0.1115	0.1422	0.1771	-	-		70	"	0.2088	0.2748
	80	"	"	0.1209	0.1544	0.1925	-	-		80	"	0.2219	0.2923
	90	"	"	0.1305	0.1667	0.2080	-	-		90	"	0.2351	0.3098
	100	"	"	0.1400	0.1790	0.2236	-	-		100	"	0.2484	0.3275
	110	"	0.1135	0.1496	0.1914	0.2394	-	-		110	"	0.2617	0.3452
150	"	0.1427	0.1886	0.2421	-	-	-	150	0.2294	0.3154	0.4169		
6"	40	0.1296	0.1296	0.1296	0.1296	0.1296	0.1628	0.2243	10"	40	0.2160	0.2160	0.2160
	50	"	"	"	"	"	0.1794	0.2475		50	"	"	0.2256
	60	"	"	"	"	0.1345	0.1961	0.2710		60	"	"	0.2407
	70	"	"	"	"	0.1459	0.2129	-		70	"	"	0.2558
	80	"	"	"	"	0.1573	0.2299	-		80	"	"	0.2711
	90	"	"	"	0.1359	0.1688	0.2469	-		90	"	0.2177	0.2863
	100	"	"	"	0.1451	0.1804	0.2641	-		100	"	0.2292	0.3016
	110	"	"	"	0.1543	0.1920	0.2814	-		110	"	0.2408	0.3170
150	"	"	0.1502	0.1917	0.2389	-	-	150	"	0.2874	0.3790		
7"	40	0.1512	0.1512	0.1512	0.1512	0.1512	0.1512	0.1987	**10' wide covers 8" or thicker require only minimum reinforcing, except 8" thickness, 150 psf = 0.1759				
	50	"	"	"	"	"	0.1580	0.2171					
	60	"	"	"	"	"	0.1713	0.2356					
	70	"	"	"	"	"	0.1846	0.2542					
	80	"	"	"	"	"	0.1981	0.2729					
	90	"	"	"	"	"	0.2216	0.2917					
	100	"	"	"	"	0.1546	0.2251	0.3107					
	110	"	"	"	"	0.1638	0.2387	0.3298					
150	"	"	"	0.1618	0.2010	0.2938	-						

*All 5' wide covers require only minimum reinforcing; except 4" thickness, 150 psf = 0.0979

Table 135-28. Heavy tank lid designs for 2-5000 lb loads 4' oc plus dead weight of slabs. Sectional area of steel required,

Span	Slab Thickness						
	4"	5"	6"	7"	8"	9"	10"
4'	0.3539	0.2342	0.1782	0.1512	0.1728	0.1944	0.2160
5'	0.4325	0.2816	0.2138	0.1739	"	"	"
6'	0.5206	0.3321	0.2513	0.2046	0.1738	"	"
7'	-	0.3859	0.2910	0.2370	0.2015	"	"
8'	-	0.4433	0.3329	0.2711	0.2308	0.2024	"
9'	-	0.5049	0.3772	0.3069	0.2166	0.2298	"
10'	-	0.5711	0.4239	0.3447	0.2941	0.2586	0.2323
12'	-	0.7203	0.5255	0.4261	0.3639	0.3207	0.2889
14'	-	-	0.6393	0.5161	0.4407	0.3890	0.3512
16'	-	-	0.7677	0.6154	0.5249	0.4638	0.4194

CHAPTER 136 STEEL COLUMN AND BEAM SELECTION

The load tables are for columns and beams of 36 ksi yield stress steel for all shape categories. All loads are tabulated in kips, 1000 lb.

Columns

Tabular loads were computed for axially loaded members having the effective unsupported lengths, KL , indicated at the left of each table. The effective length, KL , is the actual unbraced length, L ft, multiplied by the factor K . K depends on the column's end restraint: both ends pinned, $K = 1$; one end pinned & one end fixed, $K = 0.7$; both ends fixed, $K = 0.5$; one end fixed and one end free, $K = 2$.

The heavy horizontal lines in the tables indicate $KL/r = 120$; r is the radius of gyration. Load values are omitted when KL/r exceeds 200.



The I-beam columns are assumed to fail around the y-axis. If a column is braced along the y-axis, the allowable load for failure around the x-axis is the value in the load table multiplied by the ratio

of r_x to r_y , from the properties section at the bottom of each table. Failure around the y-axis for the shortened column length should also be checked.

Beams

Tabular loads, computed for simple pinned end beams, give the total allowable uniformly distributed loads in kips for laterally supported beams. Loads may be read directly from the tables when the distance between points of lateral support of the top (compression) flange does not exceed L_c , ft, listed for each beam. When the unbraced length is between L_c and L_u , multiply the load by $22/24$. Do not use these tables for beams with unbraced lengths greater than L_u , ft.

The allowable bending stress for compact shapes is 24 ksi. A reduced stress for noncompact shapes is shown in parentheses at the bottom of the load column where it applies. All beams of the same depth have the same deflection at the allowable load. Deflection may be reduced proportionally to a load less than the allowable load.

The table of Reaction Values at the bottom of each load table may be used for connection design. U is the maximum web shear in kips. R is the maximum end reaction for $3\frac{1}{2}$ " of bearing, in kips. R_1 is the increase in R for each additional inch of bearing, in kips. N_e is the length of bearing to develop the maximum shear V , in inches.

Loads above the heavy lines in the tables are limited by web shear.

Table 136-1. Axial column load in kips, W & M shapes.

Name		W8						W6						W5		W4	M8		M6		M5	M4
Width	8		6½		5½		6			4			5		4	8		6		5	4	
lb/ft	35	31	28	24	20	17	25	20	15.5	16	12	8.5	18.5	16	13	34.3	32.6	22.5	20	18.9	13	
Effective length, KL, in feet with respect to least radius of gyration ry	6	201	178	155	133	104	88	137	109	84	75	55	38	97	83	62	195	185	120	107	96	60
	7	197	174	150	128	98	83	132	105	81	69	50	34	92	79	57	190	180	115	103	91	54
	8	191	169	144	123	93	78	126	100	77	62	44	30	86	74	51	184	175	109	98	85	48
	9	186	164	138	118	86	72	120	96	73	54	38	25	81	69	45	178	170	103	92	78	42
	10	180	159	132	113	79	66	114	91	69	46	31	21	75	64	39	172	164	96	87	71	35
	11	174	154	125	107	72	60	108	85	65	38	26	17	68	58	32	165	158	89	81	64	29
	12	168	148	118	101	65	53	101	80	60	32	21	14	62	52	27	158	151	82	74	56	24
	13	162	142	111	94	56	46	94	74	55	27	18	12	54	46	23	151	144	74	68	48	21
	14	155	136	103	88	49	39	86	68	50	23	16	10	47	39	20	143	137	66	61	42	18
	15	148	130	95	81	42	34	78	61	45	20	14		41	34	17	135	130	57	53	36	15
	16	141	123	86	73	37	30	70	54	39	18			36	30	15	127	122	50	47	32	
	17	133	117	78	66	33	27	62	48	35				32	27		118	114	45	41	28	
	18	125	110	69	59	29	24	55	43	31				28	24		109	106	40	37	25	
	19	117	102	62	53	26	21	49	39	28				26	21		100	98	36	33	23	
	20	109	95	56	47	24	19	45	35	25				23	19		91	89	32	30		
	22	91	79	46	39			37	29	21							75	73	27	25		
	24	76	66	39	33			31	24	17							63	62				
	26	65	57	33	28												54	52				
	28	56	49														46	45				
	30	49	42														40	39				
	32	43	37																			
Properties																						
Area A, in ²	10.3	9.12	8.23	7.06	5.89	5.01	7.35	5.88	4.56	4.72	3.54	2.51	5.43	4.70	3.82	10.1	9.58	6.62	5.89	5.55	3.81	
Ix, in ⁴	126	110	97.8	82.5	69.4	56.6	53.3	41.5	30.1	31.7	21.7	14.8	25.4	21.3	11.3	116	114	41.2	39.0	39.0	10.5	
Iy, in ⁴	42.5	37.0	21.6	18.2	9.22	7.44	17.1	13.3	9.67	4.42	2.98	1.98	8.89	7.51	3.76	34.9	34.1	12.4	11.6	11.6	3.36	
Ratio rx/ry	1.72	1.73	2.13	2.12	2.74	2.75	1.76	1.76	1.76	2.68	2.70	2.73	1.69	1.69	1.74	1.83	1.82	1.82	1.84	1.84	1.77	
ry, in.	2.03	2.01	1.62	1.61	1.25	1.22	1.53	1.51	1.46	0.97	0.92	0.89	1.28	1.26	0.99	1.86	1.89	1.37	1.40	1.40	0.94	

Table 136-2. Axial column load in kips, extra strong pipe.

Diameter	6	5	4	3½	3
Thickness	.432	.375	.337	.318	.300
lb/ft	28.5	20.7	14.9	12.5	10.2
Effective length, KL, in feet with respect to radius of gyration	6	166	118	81	66
	7	162	114	78	63
	8	159	111	75	59
	9	155	107	71	55
	10	151	103	67	51
	11	146	99	63	47
	12	142	95	59	43
	13	137	91	54	38
	14	132	86	49	33
	15	127	81	44	29
	16	122	76	39	25
	17	116	71	34	23
	18	111	65	31	20
	19	105	59	28	18
	20	99	54	25	16
	22	86	44	21	
	24	73	37	17	
	26	62	32		
	28	54	27		
	30	47	24		
Properties					
Area A, in ²	8.40	6.11	4.41	3.68	3.02
I, in ⁴	40.5	20.7	9.61	6.28	3.89
r, in.	2.19	1.84	1.48	1.31	1.14

Table 136-3. Axial column load in kips, standard pipe.

Diameter	6	5	4	3½	3
Thickness	.280	.258	.237	.226	.216
lb/ft	18.9	14.6	10.7	9.1	7.5
Effective length, KL, in feet with respect to radius of gyration	6	110	83	59	48
	7	108	81	57	46
	8	106	78	54	44
	9	103	76	52	41
	10	101	73	49	38
	11	98	71	46	35
	12	95	68	43	32
	13	92	65	40	29
	14	89	61	36	25
	15	86	58	33	22
	16	82	55	29	19
	17	79	51	26	17
	18	75	47	23	15
	19	71	43	21	14
	20	67	39	19	12
	22	59	32	15	10
	24	51	27	13	
	26	43	23		
	28	37	20		
	30	32	17		
Properties					
Area A, in ²	5.58	4.30	3.17	2.68	2.23
I, in ⁴	28.1	15.2	7.23	4.79	3.02
r, in.	2.25	1.88	1.51	1.34	1.16

Table 136-4. Axial column load in kips, square structural tubing.

Size	6x6			5x5			4x4		
Thick.	3/8	5/16	1/4	3/8	5/16	1/4	3/8	5/16	1/4
lb/ft	27.0	23.0	18.8	21.9	18.7	15.4	16.8	14.5	12.0
Effective length, KL, in feet with respect to radius of gyration	6	157	134	110	124	107	88	91	79
	7	154	132	108	121	104	86	87	76
	8	151	129	106	117	101	83	83	72
	9	147	126	103	113	98	81	79	69
	10	144	123	101	109	94	78	74	65
	11	140	120	98	105	91	75	69	61
	12	136	116	95	101	87	72	64	57
	13	131	113	93	96	83	69	59	52
	14	127	109	90	91	79	66	53	47
	15	122	105	87	86	75	62	47	42
	16	118	101	83	81	70	59	42	37
	17	113	97	80	75	66	55	37	33
	18	108	93	77	69	61	51	33	30
	19	102	88	73	63	56	47	29	27
	20	97	84	69	57	51	43	27	24
	22	85	74	62	47	42	35	22	20
	24	73	64	54	40	35	30	18	17
	26	62	54	46	34	30	25		
	28	54	47	39	29	26	22		
	30	47	41	34	25	22	19		
	32	41	36	30					
	34	36	32	27					
	36	32	28	24					
	38		25	21					
Properties									
Area A, in ²	7.95	6.77	5.54	6.45	5.52	4.54	4.95	4.27	3.54
I, in ⁴	40.5	35.5	29.9	22.0	19.5	16.6	10.2	9.23	8.00
r, in.	2.26	2.29	2.32	1.85	1.88	1.91	1.44	1.47	1.50

Table 136-5. Total uniformly distributed beam loads in kips, M shapes.

Name	M14	M12	M10			M8	M7	M6
Width	4	3 1/8	5 7/8	5 3/4	2 3/4	2 1/4	2 1/8	1 7/8
lb/ft	17.2	11.8	29.1	22.9	9	6.5	5.5	4.4
L _c , ft	3.6	2.7	6.3	6.1	2.6	2.4	2.2	1.9
L _u , ft	4.1	3.1	10.8	10.5	2.7	2.5	2.5	2.4
Span, ft	8	42	24.0	53	47	15.5	9.2	6.9
	9	37	21.3	47	42	13.8	8.2	6.1
	10	33	19.2	42	37	12.4	7.4	5.5
	11	30	17.5	38	34	11.3	6.7	5.0
	12	28	16.0	35	31	10.3	6.2	4.6
	13	26	14.8	32	29	9.6	5.7	4.2
	14	24	13.7	30	27	8.9	5.3	3.9
	15	22	12.8	28	25	8.3	4.9	3.7
	16	21	12.0	26	23	7.8	4.6	
	17	19	11.3	25	22	7.3	4.3	
	18	18	10.7	23	21	6.9		
	19	17	10.1	22	19	6.5		
	20	16	9.6	21	18	6.2		
	21	16	9.1	20	18	5.9		
	22	15	8.7					
	23	14	8.3					
	24	14	8.0					
	25	13	7.7					
	26	13						
	27	12						
	28	12						
	29	11						
	30	11						
Properties and Reaction Values								
S, in ³	21.1	12.0	26.6	23.6	7.8	4.6	3.4	2.4
V, kips	42.6	30.8	61.2	34.7	22.8	15.7	13.0	9.9
R, kips	23.4	19.4	50.4	28.6	17.0	14.6	13.6	11.9
R _i , kips	5.7	4.8	11.5	6.5	4.2	3.6	3.5	3.1
R _e , in.	6.9	5.9	4.4	4.4	4.9	3.8	3.3	2.8

Table 136-6. Total uniformly distributed beam loads in kips, W shapes.

Name		W14						W12										W10			
Width		6 ^{3/4}	6 ^{3/4}	6 ^{3/4}	5	5	Defl	6 ^{5/8}	6 ^{1/2}	6 ^{1/2}	4	4	4	4	Defl	8	8	8	5 ^{3/4}		
lb/ft		38	34	30	26	22		36	31	27	22	19	16.5	14		45	39	33	29		
L _c , ft		7.2	7.1	7.1	5.3	5.3		in.	6.9	6.9	6.9	4.3	4.2	4.1		3.5	in.	8.5	8.4	8.4	6.1
L _u , ft		11.4	10.1	8.6	7.0	5.7		13.4	11.6	10.1	6.4	5.3	4.3	4.2		22.7	19.6	16.4	13.2		
Span, ft	8	109	97	83	70	58	0.11	92	79	68	50	42	35	29	0.13	98	84	69	61		
	9	97	86	74	62	51	0.14	81	70	60	45	37	31	26	0.17	87	75	61	54		
	10	88	78	66	56	46	0.18	73	63	54	40	34	28	23	0.21	79	68	55	49		
	11	80	71	60	51	42	0.21	66	57	49	36	31	25	21	0.25	71	61	50	44		
	12	73	65	55	47	39	0.26	61	52	45	33	28	23	19	0.30	65	56	46	41		
	13	67	60	51	43	36	0.30	56	48	42	31	26	21	18	0.35	60	52	42	37		
	14	63	56	47	40	33	0.35	52	45	39	28	24	20	16	0.41	56	48	39	35		
	15	58	52	44	37	31	0.40	49	42	36	27	22	18	15	0.47	52	45	37	32		
	16	55	49	41	35	29	0.45	46	39	34	25	21	17	14	0.53	49	42	34	30		
	17	51	46	39	33	27	0.51	43	37	32	23	20	16	13	0.60	46	40	32	29		
	18	49	43	37	31	26	0.57	40	35	30	22	18	15	13	0.67	44	38	31	27		
	19	46	41	35	30	24	0.64	38	33	28	21	17	14	12	0.75	41	36	29	25		
	20	44	39	33	28	23	0.71	36	31	27	20	17	14	11	0.83	39	34	28	24		
	21	42	37	32	27	22	0.78	35	30	26	19	16	13	11	0.91	37	32	26	23		
	22	40	35	30	26	21	0.86	33	28	24	18	15	12	10	1.00	36	31	25	22		
	23	38	34	29	24	20	0.94	32	27	23	17	14	12	10	1.09						
	24	36	32	28	23	19	1.02	30	26	22	16	14	11	9	1.19						
	25	35	31	27	22	18	1.11	29	25	21	16	13	11	9	1.29						
	26	34	30	25	22	18	1.20														
	27	32	29	25	21	17	1.29														
28	31	28	24	20	17	1.39															
29	30	27	23	19	16	1.49															
30	29	26	22	19	15	1.60															
		(23.7)						(23.7)										(23.6)			
Properties and Reaction Values																					
S, in ³	54.7	48.6	41.9	35.1	28.9		46.0	39.5	34.2	25.3	21.3	17.6	14.8		49.1	42.2	35.0	30.8			
V, kips	64	58	54	51	46		54.1	46.5	41.1	46.4	41.8	40.0	34.2		51	46	41	42.8			
R, kips	39	35	33	31	28		37.6	32.2	28.4	31.2	28.0	26.8	22.7		44	40	35	35.6			
R _i , kips	8.5	7.7	7.3	6.9	6.9		8.2	7.2	6.4	7.0	6.4	6.2	5.3		9.5	8.6	7.9	7.8			
N _g , in.	6.5	6.5	6.4	6.5	6.4		5.5	5.5	5.5	5.7	5.7	5.6	5.6		4.2	4.2	4.2	4.4			

Table 136-6. Continued.

Name		W10							W8							W6				
Width		5 ^{3/4}	5 ^{3/4}	4	4	4	4	Defl	6 ^{1/2}	6 ^{1/2}	5 ^{1/2}	5 ^{1/2}	4	4	4	Defl	4	4	4	Defl
lb/ft		25	21	19	17	15	11.5		28	24	20	17	15	13	10		16	12	8.5	
L _c , ft		6.1	6.1	4.2	4.2	4.2	3.8		6.9	6.9	5.6	5.5	4.2	4.2	4.2		4.3	4.2	4.2	
L _u , ft		11.4	9.1	7.2	6.0	5.0	4.3		17.4	15.1	11.3	9.4	7.2	5.9	4.7		12.1	8.6	6.1	
Span, ft	8	53	43	37	32	27	20.5	0.16	48	41	34	28	23	19.8	15.3	0.20	20	14.5	9.9	0.26
	9	47	38	33	28	24	18.2	0.20	43	37	30	25	21	17.6	13.6	0.25	18	12.9	8.8	0.34
	10	42	34	30	25	22	16.4	0.25	38	33	27	22	18	15.8	12.2	0.31	16	11.6	7.9	0.41
	11	38	31	27	23	20	14.9	0.30	35	30	24	20	17	14.4	11.1	0.38	14	10.5	7.2	0.50
	12	35	28	25	21	18	13.7	0.36	32	27	22	18	15	13.2	10.2	0.45	13	9.7	6.6	0.60
	13	32	26	23	19	17	12.6	0.42	29	25	20	17	14	12.2	9.4	0.52	12	8.9	6.1	0.70
	14	30	24	21	18	15	11.7	0.49	27	23	19	16	13	11.3	8.7	0.61				
	15	28	22	20	17	14	10.9	0.56	25	22	18	15	12	10.6	8.1	0.70				
	16	26	21	18	16	13	10.3	0.64	24	20	17	14	11	9.9	7.6	0.79				
	17	24	20	17	15	13	9.7	0.72	22	19	16	13	11	9.3	7.2	0.90				
	18	23	19	16	14	12	9.1	0.80												
	19	22	18	15	13	11	8.6	0.90												
	20	21	17	15	13	11	8.2	0.99												
	21	20	16	14	12	10	7.8	1.09												
	22	19	15	13	11	10	7.5	1.20												
							(23.5)								(23.5)					(23.3)
Properties and Reaction Values																				
S, in ³	26.5	21.5	18.8	16.2	13.8	10.5		24.3	20.8	17.0	14.1	11.8	9.9	7.8		10.2	7.3	5.1		
V, kips	36.8	34.5	37.2	35.2	33.4	25.8		33.3	28.2	29.3	26.7	28.8	26.7	19.5		23.6	20.0	14.4		
R, kips	30.6	28.4	30.0	28.4	26.8	20.7		34.1	28.9	29.3	26.8	28.5	26.4	19.2		30.7	26.4	19.2		
R _t , kips	6.8	6.5	6.8	6.5	6.2	4.9		7.7	6.6	6.7	6.2	6.6	6.2	4.6		7.0	6.2	4.6		
N _g , in.	4.4	4.4	4.6	4.6	4.6	4.6		3.4	3.4	3.5	3.5	3.5	3.5	3.6		2.5	2.5	2.4		

140 CONSTRUCTION

CHAPTER 141—FARM BUILDING CONSTRUCTION SYSTEMS

STUD FRAME CONSTRUCTION

Platform Framing (Fig 141-1)

In platform frame construction, the subfloor extends to the outside edges of the building and provides a platform on which exterior walls and interior partitions are erected. Platform framing is the most common for one-story houses. It is also used alone or in combination with balloon construction for two-story structures.

Platform construction is easy to erect because it provides a flat surface at each floor level to work on. It also adapts easily to prefabrication. With platform framing, it is common to assemble the wall framing on the floor and then tilt the entire unit into place.

Balloon Framing (Fig 141-2)

In balloon frame construction both studs and first-floor joists rest on the anchored sill. The second-floor joists bear on a 1 x 4 ribbon (or ribband) let into the inside edges of the studs. Balloon framing is preferred for two-story buildings with an exterior veneer of brick, stone, or stucco, as there is less movement between the wood framing and the veneer.

With solid masonry exterior walls, balloon framing for interior bearing partitions is desirable. It eliminates possible variations in settlement between exterior walls and interior supports.

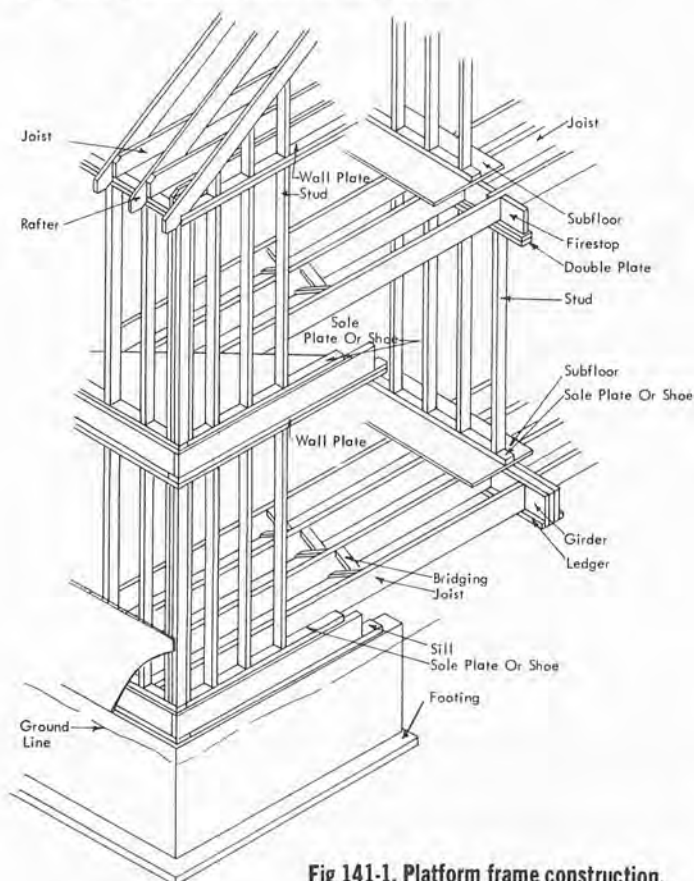


Fig 141-1. Platform frame construction.

Table 141-1
RECOMMENDED NAILING SCHEDULE
For Common Nails

Joist to sill or girder, toe nail.....	3-8d
Bridging to joist, toe nail each end.....	2-8d
Ledger strip on girder.....	3-16d
at each joist	
1" x 6" subfloor or less to each joist, face nail.....	2-8d
Over 1" x 6" subfloor to each joist, face nail.....	3-8d
2" subfloor to joist or girder, blind and face nail.....	2-16d
Sole plate to joist or blocking, face nail.....	16d @ 16" oc
Top plate to stud, end nail.....	2-16d
Stud to sole plate, toe nail.....	4-8d
Doubled studs, face nail.....	16d @ 24" oc
Doubled top plates, face nail.....	16d @ 16" oc
Top plates, laps and intersections, face nail.....	2-16d
Continuous header, two pieces.....	16d @ 16" oc
along each edge	
Ceiling joists to plate, toe nail.....	3-8d
Continuous header to stud, toe nail.....	4-8d
Ceiling joists, laps over partitions, face nail.....	3-16d
Ceiling joists to parallel rafters, face nail.....	3-16d
Rafter to plate, toe nail.....	3-8d
1-inch brace to each stud and plate, face nail.....	2-8d
1" x 8" sheathing or less to each bearing, face nail.....	2-8d
Over 1" x 8" sheathing to each bearing, face nail.....	3-8d
Built-up corner studs.....	16d @ 24" oc
Built-up girders and beams.....	20d @ 32" oc
along each edge	

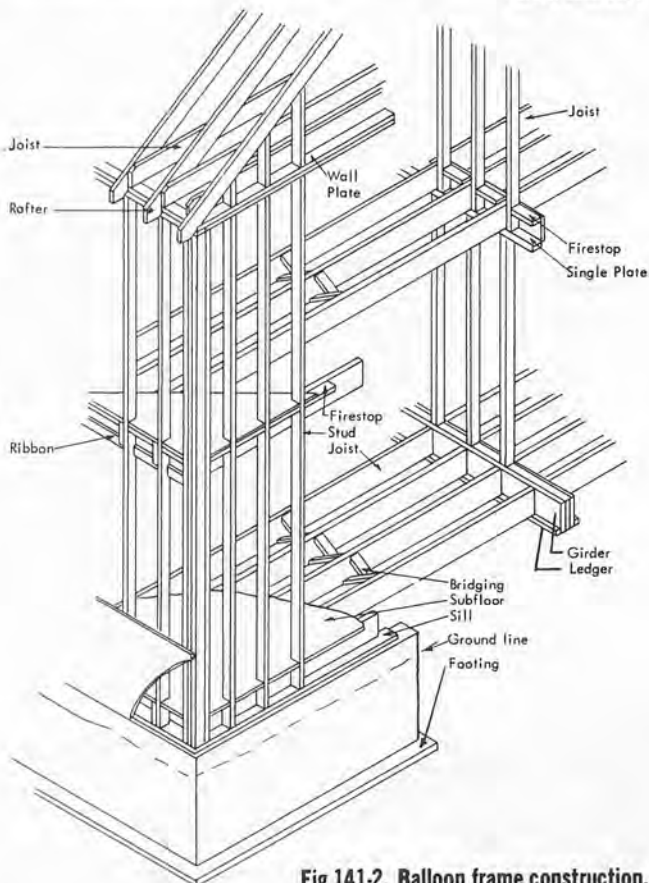


Fig 141-2. Balloon frame construction.

Floor Framing

Floor framing consists of sills, girders, joists and subflooring, with all members tied together to support floor loads and exterior walls.

Sills on Foundation Walls—Sills on continuous foundation walls are usually 2" thick lumber set on the walls to provide full and even bearing. They are anchored to foundation walls with 1/2" bolts 8' apart with at least 2 bolts in each sill piece. Embed bolts at least 6" in poured concrete and at least 15" in masonry units. (Fig 141-3)

Girders—Girders support joists. They are solid timbers or members built-up of 2" pieces nailed together with the wide faces vertical. See Figure 141-4. Girders are fastened together with 1 row of 20d nails 32" o.c. along each edge. Glue-laminated members also are frequently used. Beams and girders that are not continuous are tied together across supports. A bearing of 4" on supports is recommended.

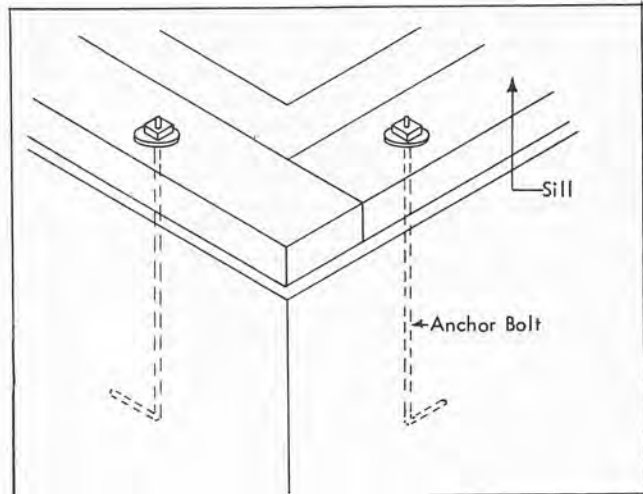


Fig 141-3. Anchoring sill to continuous foundation wall.

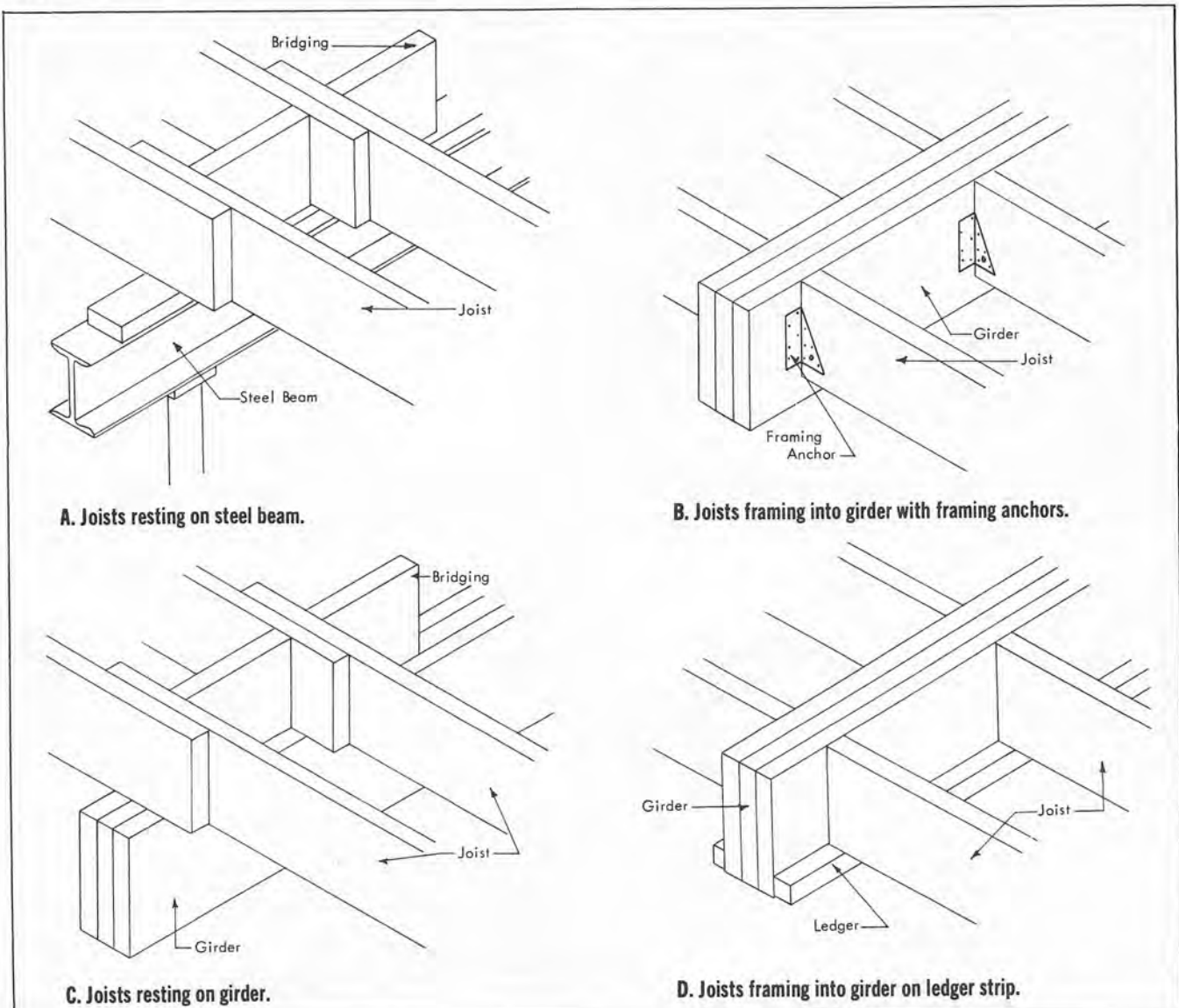


Fig 141-4. Joist and girder framing.

Joists—Joists are beams that support subflooring or ceilings. They are placed with top edges even for installing the subfloor and finished floor. Align the bottom edges of ceiling joists for an even ceiling. If joists carry both ceilings and subfloors, shims may be needed to align one or the other. Bearing for joists should not be less than 1 1/2" on wood or metal, and 3" on masonry.

Avoid notches for piping, in the top or bottom of joists, that exceed 1/6 the joist depth and/or are in the middle third of the span. Drill holes for piping or electric cables no closer than 2" to the top or bottom of the joist; hole diameters should not exceed 1/3 of the joist depth. Where joists are notched on the ends, the notch should not exceed one fourth the joist depth.

Bridging—Brace joists to prevent them from buckling under load. Bridging—diagonal struts or solid blocks—is placed between and at right angles to joists near each end and at up to 8' o.c. Omit bridging at the ends of joists that are nailed to a header, joist band, or adjoining studs.

Framing Floor Openings (Fig 141-4E)—Proper arrangement of headers, trimmers and tail joists accomplishes framing of openings. Double trimmers and headers with header spans over 4'. Support headers over 6' long on joist hangers or framing anchors, unless they rest on a partition, beam, or wall. Support tail joists over 12' long on framing anchors, or on ledger strips not less than nominal 2x2.

Partition Support—Bearing partitions usually are placed directly over the girders or walls that support the floor framing. In general, bearing partitions at right angles to joists should not be offset from main girders or walls more than the depth of the joist, unless the joists are designed to carry the extra load. When non-bearing partitions are parallel to joists, joists under the partitions are doubled.

Sub-Flooring—Wood sub-flooring is usually square-edge or tongued-and-grooved (T&G) boards.

Diagonal sub-flooring permits the finish floor to be either parallel or at right angles to the joists, and provides lateral bracing and stiffness. Joints are over the joists unless boards are end-matched. Plywood subfloor may be faster to lay, and gives even better stiffness.

Finish Flooring

Subfloor Preparation—Clean the subfloor of debris. Drive in raised nails and examine the floor for proper nailing. A building paper, such as 15-1b asphalt-saturated felt, is laid over the subfloor.

Finish Hardwood or Softwood T&G Floor Boards—Install finish flooring in the opposite direction to the joists. An expansion joint, covered later by the base board and base shoe, is left next to all vertical surfaces.

Start flooring strips square with the room against either sidewall. Face-nail the first piece next to the wall so nails will be covered by the moulding.

Blind nail other strips along the tongue with nails at an angle of 45 to 50 degrees with the floor, and deep enough to permit a tight match with the next piece. Square-edge strips are face-nailed, with nails set. Use 7d or 8d screw or cut steel nails spaced 10" to 12" apart.

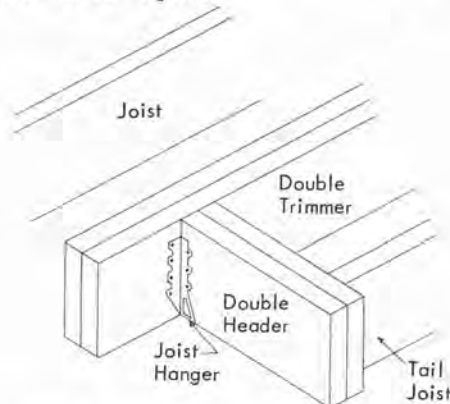


Fig 141-4E. Framing of header to trimmer by joist hanger.

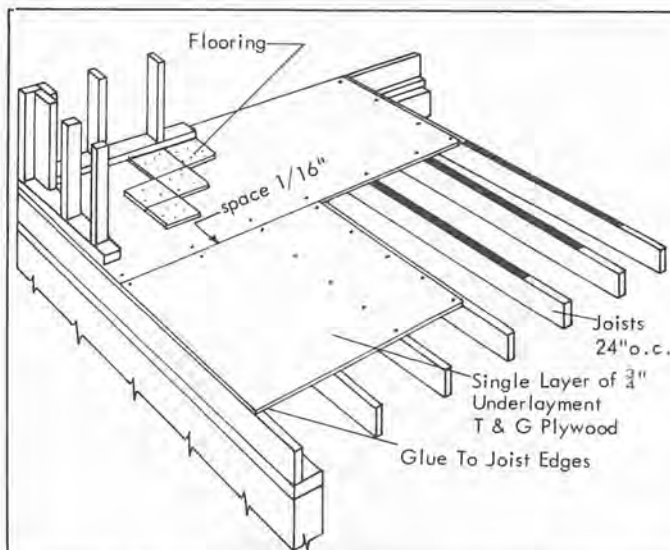


Fig 141-5. Single underlayment floor.

A combination subfloor and base for finish floor is economical and practical.

Joists—No. 2 or better Douglas fir-larch lumber 2x10 repetitive members, 24" o.c.		Allowable span	
Grade	Moist	30 live + 10 dead sleeping & attic	40 live + 10 dead other areas
No. 1	15%	17'-0"	15'-5"
	19	16'-5"	14'-11"
No. 2	15%	16'-1"	14'-7"
	19	16'-1"	14'-7"

Underlayment—single layer of 3/4" plywood T&G (interior, or interior with exterior glue)

Stagger end joints

Leave 1/16" between sheets at side and end joints

Site-applied elastomeric construction adhesive on joist faces and on T&G plywood joints

Nailing: 6d deformed shank, or 8d common, 12" spacing along all bearings
If plywood is not T&G, block under all joints

Finish—Tile, carpet, linoleum or other non-structural flooring

If subflooring is other than wood boards, nails penetrate each joist and another nail is driven between joists. Nail each strip as close as practical to the end. For appearance, end joints should be well distributed.

Plywood Base for Finish Floor—Linoleum, tile or carpet may be placed directly on plywood.

Exterior Wall Framing

Exterior walls support floor and roof loads, and resist lateral loads from wind. Wall plates, studs, and bottom anchor systems form the basic components of wall framing. In balloon framing the bottom anchor of the studs is the sill. In platform framing the sole plate or shoe is the bottom anchor. Framing for openings and bracing are also parts of the wall framing system.

Top Plates—The top plate is 2" dimension lumber nailed on top of the studs. The plate is usually a double member overlapped at wall and partition intersections.

Sole Plate or Shoe—The sole plate is a 2" piece nailed to the bottom of the studs in platform

framing, often before the wall is tipped up into place; or the studs are toe-nailed to the sole plate.

Stud Size and Spacing—Studs in exterior walls are placed with the wide faces perpendicular to direction of the wall. Studs are usually 2 x 4's in 1- and 2-story buildings. In 3-story buildings, studs in the bottom story should be at least 2 x 6's. In one-story buildings, studs may be 24" o.c., unless otherwise limited by the covering. In multi-story buildings, spacing should not exceed 16" o.c. Stud spacing is measured center to center except at corners—measure from the outside of the corner stud to the center of the first interior stud. Multiple studs at the corners provide for attaching surface materials. Fig 141-6.

Gable-End Walls—Studs in gable ends rest on wall plates and are notched and nailed to the end rafter.

Openings—A header carries loads over doors and windows. Support the header on trimmer studs, or by framing anchors for spans up to 3'. Where the opening width exceeds 6', use triple studs with each end of the header resting on two trimmer studs. Fig 141-7.

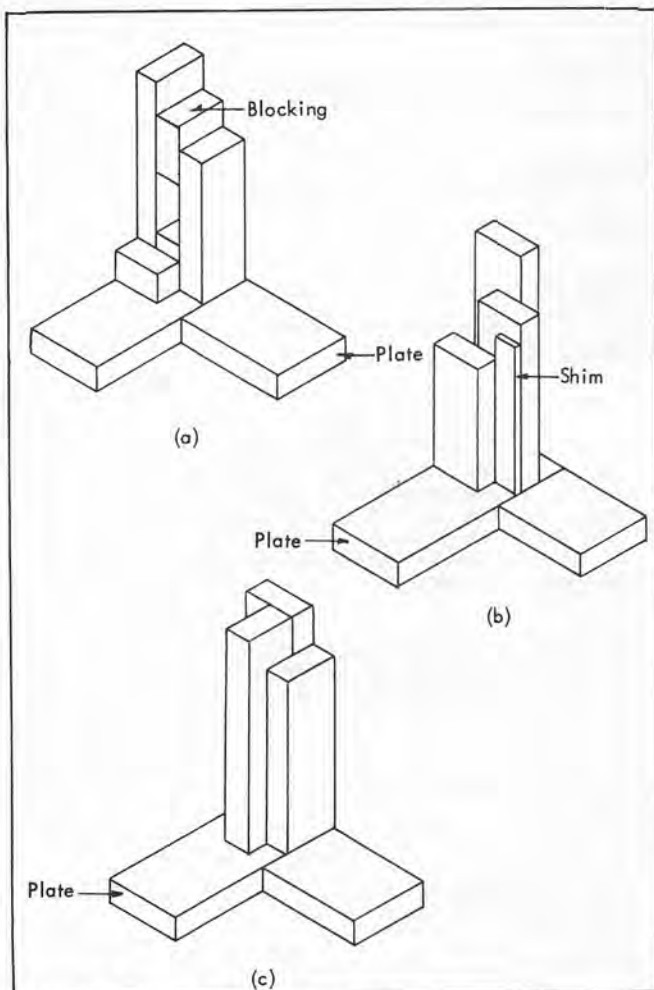


Fig 141-6. Assembly of studs at outside corner.

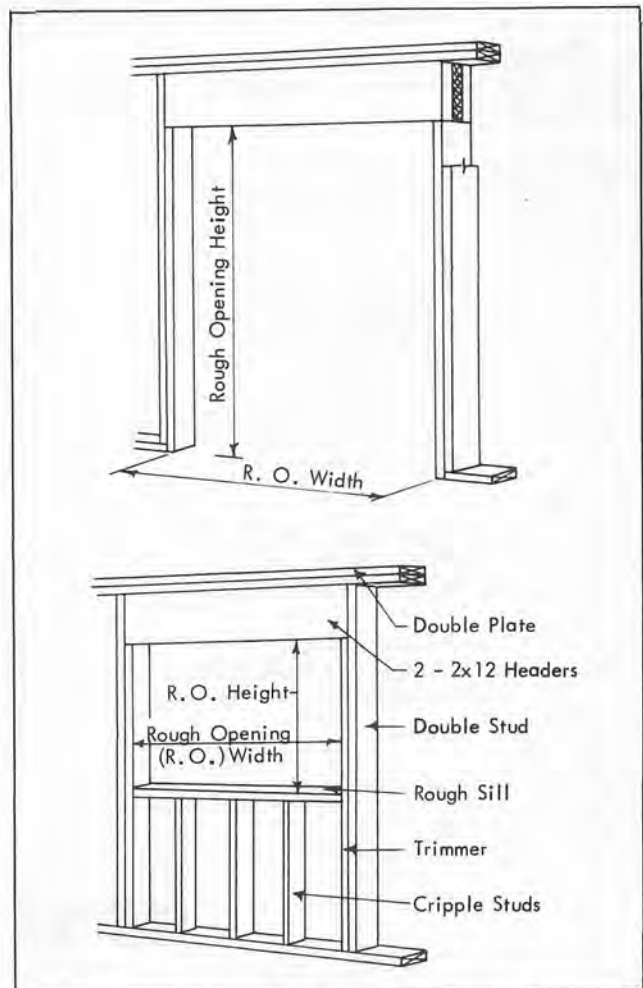


Fig 141-7. Framing around exterior wall opening using header and double studs.

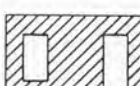
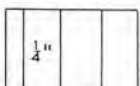
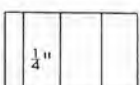
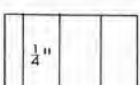
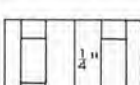
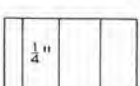
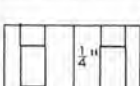
Wall Sheathing—Metal, plywood, and some wood siding can be applied in a single layer on building frames for exterior siding. Some plywood, building boards, and fiber board are rough sheathing requiring a finish siding. For weather-tight walls, cover rough sheathing on the outside with asphalt-saturated felt weighing not less than 15 lb/100 sq ft, or with other impregnated paper having equivalent water-repellent properties. Sheathing paper must not be a vapor barrier. Lap felt 4" at horizontal joints and 6" at vertical joints. Install strips of sheathing paper, about 6" inches wide, behind trim and around openings. The wall may then be completed with a finishing siding material.

Bracing—Most frame walls are strong enough to support roof loads, and to resist wind pressures perpendicular to them. Also important is resistance to end thrust or racking forces from the action

of wind on adjacent walls. The factors most likely to affect resistance to racking are: the size and locations of wall openings, the type and size of framing, sheathing material, bracing, fasteners, and moisture content of the materials.

Fig 141-8 illustrates the relative stiffness and strength of sheathing and bracing systems.

Strength and stiffness may be provided by 1" x 4" members let into the outside face of the studs at an angle of 45 degrees and nailed to top and bottom plates and studs. Where plywood or other panel material is used, and where wood sheathing boards are applied diagonally, let-in braces are not necessary. Nail sheathing to sills, headers, studs, plates or continuous headers, and to gable end rafters. Plywood or fiberboard also provide good stiffness.

EFFECT OF SHEATHING (No Openings)		Relative Rigidity	Relative Strength	EFFECT OF SHEATHING (Window and Door Openings)		Relative Rigidity	Relative Strength
	2 8d Nails Per Stud Crossing	1.0	1.0		2 8d Nails Per Stud Crossing	1.0	1.0
	2 8d Nails Per Stud Crossing	4.3	8 ⁺		2 8d Nails Per Stud Crossing	0.7	0.8
	8d Nails Spaced 3 Inches At Vertical Edges, 6 Inches On Intermediate Studs, 5 1/3 Inches On Plates	3.0	3.8		2 8d Nails Per Stud Crossing	1.4	4.0
	8d Nails Spaced 6 Inches On All Edges Of Plywood, 12 Inches On Intermediate Studs	4.8	9 ⁺	 Fiberboard	8d Nails Spaced 3 Inches At All Vertical Edges, 6 Inches On Intermediate Studs, 5 1/3 Inches On Plates. Fiberboard Used In Continuous Sheets With Nailing Studs Above And Below Openings	1.6	2.1
	6d Nails Spaced 5 Inches On All Edges Of Plywood, 10 Inches On Intermediate Studs	4.2	5.2		6d Nails Spaced 5 Inches At All Plywood Edges And 10 Inches At Intermediate Studs	2.0	2.8
	6d Nails Spaced 2 1/2 Inches On All Edges Of Plywood, 5 Inches On Intermediate Studs	5.9	7.0		6d Nails Spaced 5 Inches At All Plywood Edges And 10 Inches At Intermediate Studs	2.0	2.8
	Glued To Frame	14.4	8.6		Glued To Frame	3.7	4.0

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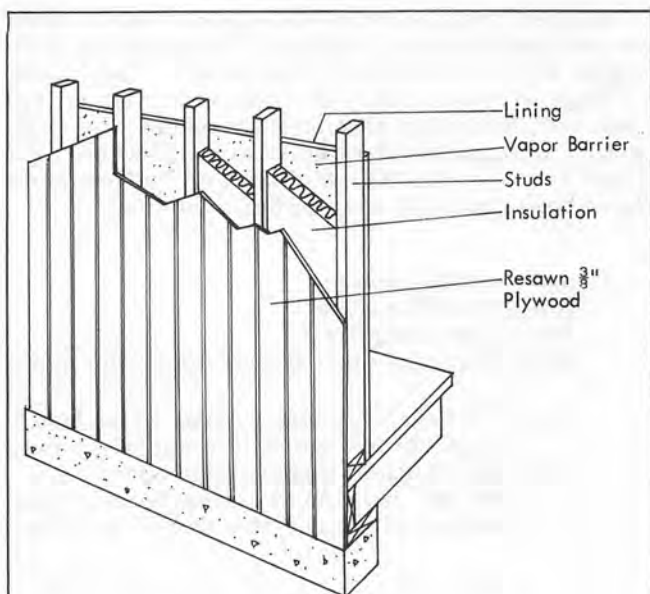

1x8 Boards


Plywood

 1/4"
Plywood

 3/8"
Plywood

Fig 141-8. Rigidity and strength of sheathing.



Sill—2x6 or 2x8 preservative treated, $\frac{1}{2}$ "x6" anchor bolt 8" o.c.
 Studs—Stud grade DF or SYP, 16" o.c.
 Sheathing—none
 Siding—Texture 1-11 resawn plywood; or $\frac{3}{8}$ " plywood with battens, 16" o.c.
 Finish: penetrating oil stain with 5% penta
 8d non-corrosive casing or siding nails 6" o.c. at panel edges, 12" o.c. at intermediate supports
 Nail shiplap joints with one row of nails at a slight angle thru the joint
 Caulking needed only at inside and outside corners
 Insulation—3" fiberglass or equivalent
 Vapor Barrier—4 mil polyethylene
 Lining— $\frac{1}{2}$ " gypsum wallboard

Fig 141-9. Single skin exterior wall.

A combined plywood sheathing and siding is economical and practical.

Partition Framing (Fig 141-10)

There are two types of interior partitions—bearing partitions, which support floors, ceilings or roofs, and non-bearing partitions, which carry only the weight of the partition.

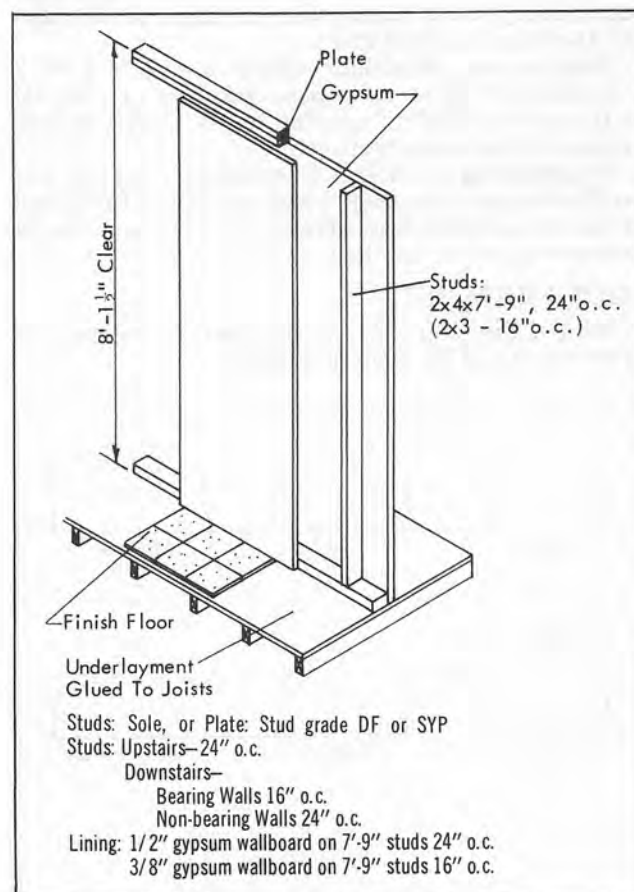


Fig 141-11. Economical residential partition framing.

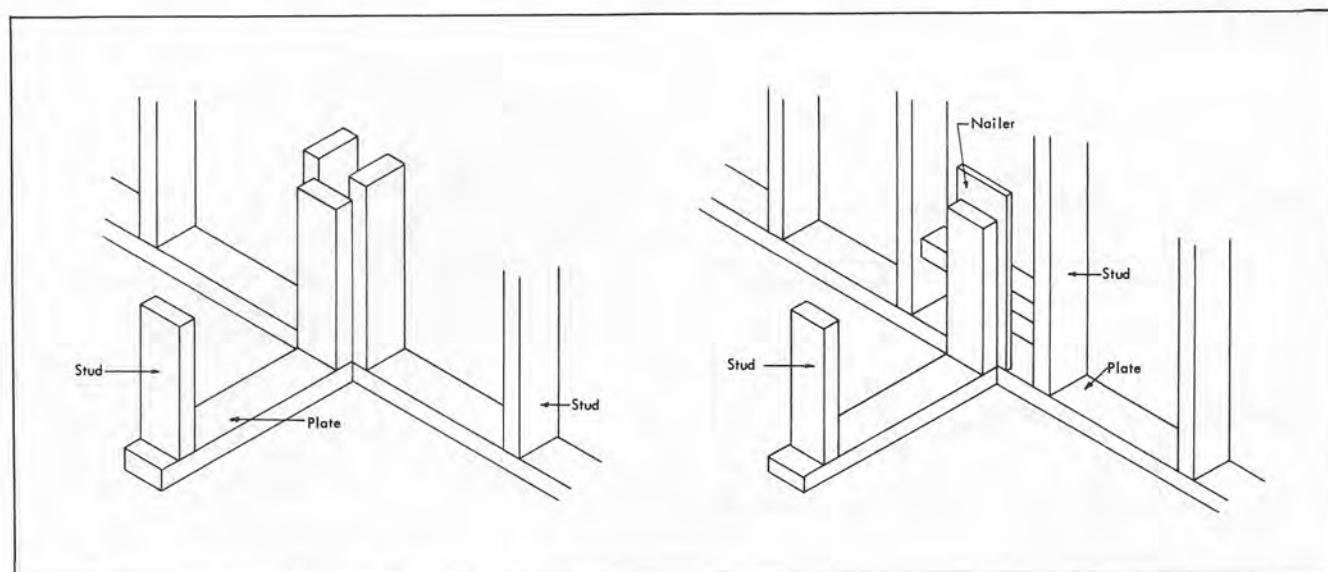


Fig 141-10. Assembly of studs where partition meets wall.

Bearing Partitions—2 x 4 studs are set with the wide dimension perpendicular to the partition and capped with a double top plate lapped or tied into exterior walls at points of intersections. Studs supporting floors should be 16" o.c.; those supporting ceilings and roofs may be 24" o.c. Where openings occur, carry loads across the openings on headers like those for exterior walls.

Non-Bearing Partitions—Studs are 2 x 3 or 2 x 4, set with wide faces perpendicular or parallel to the partition. Stud spacing is 16" - 24", unless limited by the wall covering.

Firestopping—Concealed spaces in wood framing are firestopped with wood blocking, accurately fitted to fill the opening and arranged to prevent drafts from one space to another.

ROOF FRAMING

Roof Type—Fig 141-12 illustrates roof shapes commonly used for farm buildings.

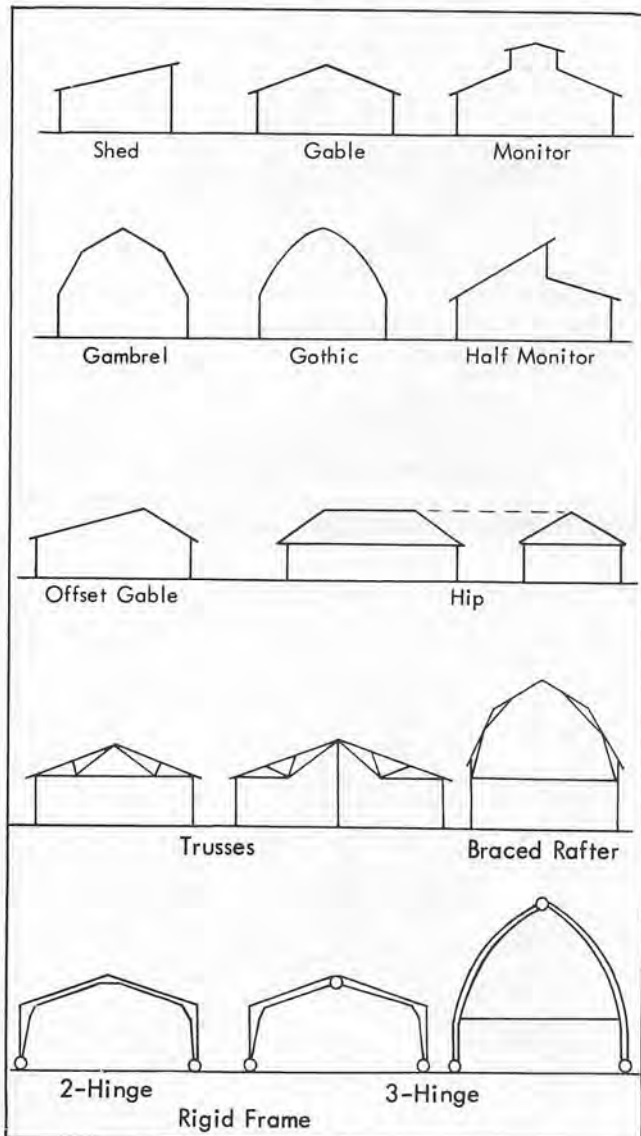


Fig 141-12. Roof types.

A shed roof is simple to construct and is used on relatively narrow buildings. Gable and hip roofs adapt to many structures, particularly those where ceilings are used. The hip roof is used for its appearance and no gable-end maintenance. Gambrel, gothic, and gable rigid frames are used where high head room is needed. Monitors and half monitors have been used primarily for better lighting.

Common roofing terms:

Ridge: Top line of roof.

Eave: Lower edge of roof.

Rake: Exposed edge of roof, as at the gable end.

Fascia Board: Trim board nailed to the fascia cut—the vertical cut at the end of a rafter.

Soffit or Plancher Board: Trim board nailed under the eave on the plancher cut—the horizontal cut under the end of a rafter.

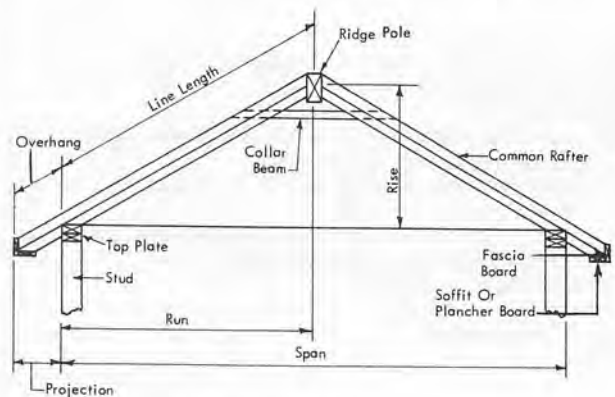


Fig 141-13. Gable roof.

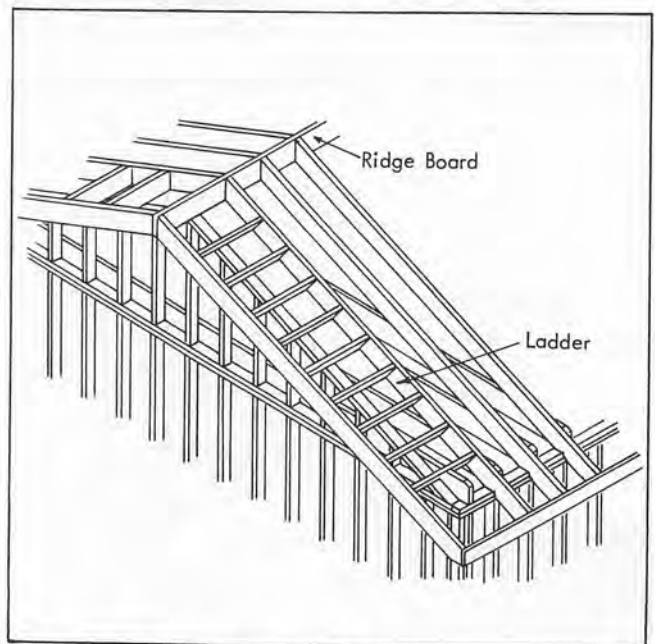


Fig 141-14. Roof framing for overhang at gable end.

Gable Roof—Fig 141-13 illustrates the parts of a gable roof. **Span** is the width between the outer edges of the plates. **Run** is one half of the span. **Rise** is the vertical distance from the top of the plate to the workline at the ridge. The run and the rise are the two legs of a right triangle; the rafter length along the workline is the hypotenuse. **Roof pitch** is the rise divided by the span. **Roof slope** is rise divided by the run.

Collar Beams—Install 1 x 6 collar beams in the upper third of the attic space to every third pair of rafters on pitched roofs, to tie the ridge framing together during high winds.

Ridge Pole or Board—Ridge poles are 1" or 2" lumber placed between rafters at the ridge. They are 2" deeper than the rafter to permit full contact. Rafters should butt directly opposite each other and be nailed to the ridge board. Notch rafters to fit

exterior wall plates and fasten securely.

Hip roof—Components of the hip roof are shown in Fig 141-15.

Valley rafters at the intersection of two roof areas are twice as thick and 2" deeper than the common rafters, to permit full bearing for the beveled end. Where ridges are at different elevations, provide vertical support for the interior end of the lower ridge board.

Hip rafters may be the thickness of common rafters, but should be 2 inches deeper.

Flat Roofs—In buildings with flat roofs the rafters or roof joists usually serve as ceiling joists for the space below. They are nailed to exterior walls. Where joists meet over interior partitions they should be nailed to plates and to each other. Avoid flat roofs as they are a major source of leaks; provide at least 3/4"/ft slope if possible.

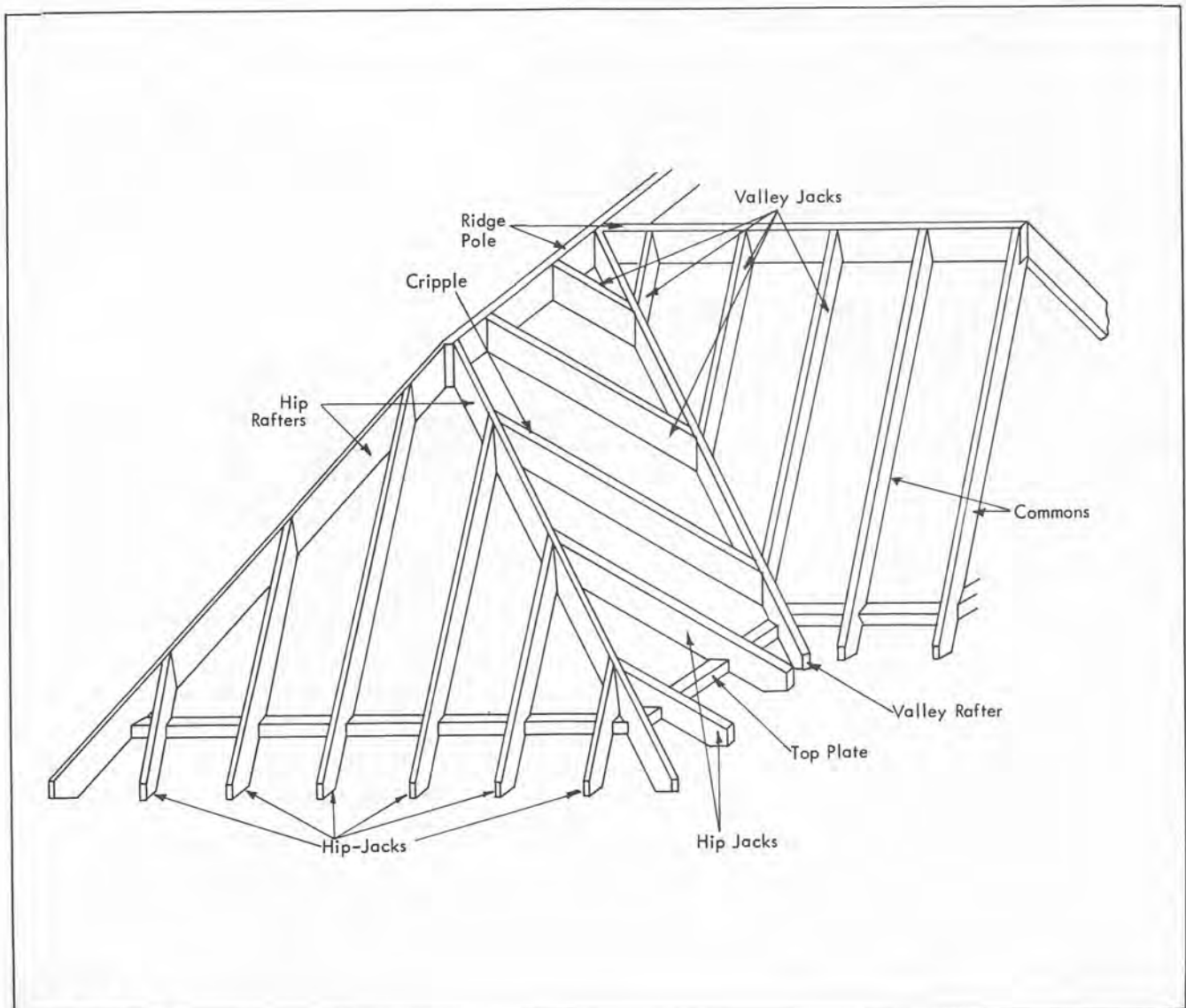


Fig 141-15. Rafters.

Cutting Common Rafter—

Terminology—

1. **Workline:** The line on the rafter extending from the point of the birdsmouth (outer edge of top of plate) to the ridge. It is parallel to the rafter length. The workline completes the triangle formed by the rise and run.
2. **Plumb cut:** Vertical cut at the top of the rafter.
3. **Birdsmouth:** Notch cut to fit the plate.
4. **Fascia Cut:** Vertical cut at the lower end of the rafter overhang.
5. **Plancher Cut:** Horizontal cut at the lower end of the rafter overhang.

Procedure—

1. Lay out workline. Locate the workline on the rafter so the birdsmouth provides full bearing of the rafter on the plate. The top cut of the birdsmouth is as long as the width of the plate. Using appropriate settings on the square, and measuring from the inner edge of the rafter, locate the workline.
2. Determine square setting. A horizontal square setting of 12 is usually used for marking rafters. If roof pitch is given, the vertical square setting can be determined by using the roof pitch equation. The horizontal square setting then is the run. A sample calculation is shown in Figure 141-17 for a roof pitch of 1/4 and a building span of 26'.
3. Mark plumb cut.
4. Measure rafter length on workline. The sample calculation applies.
5. Mark birdsmouth, fascia cut, and plancher cut. Length of overhang can be varied as desired.

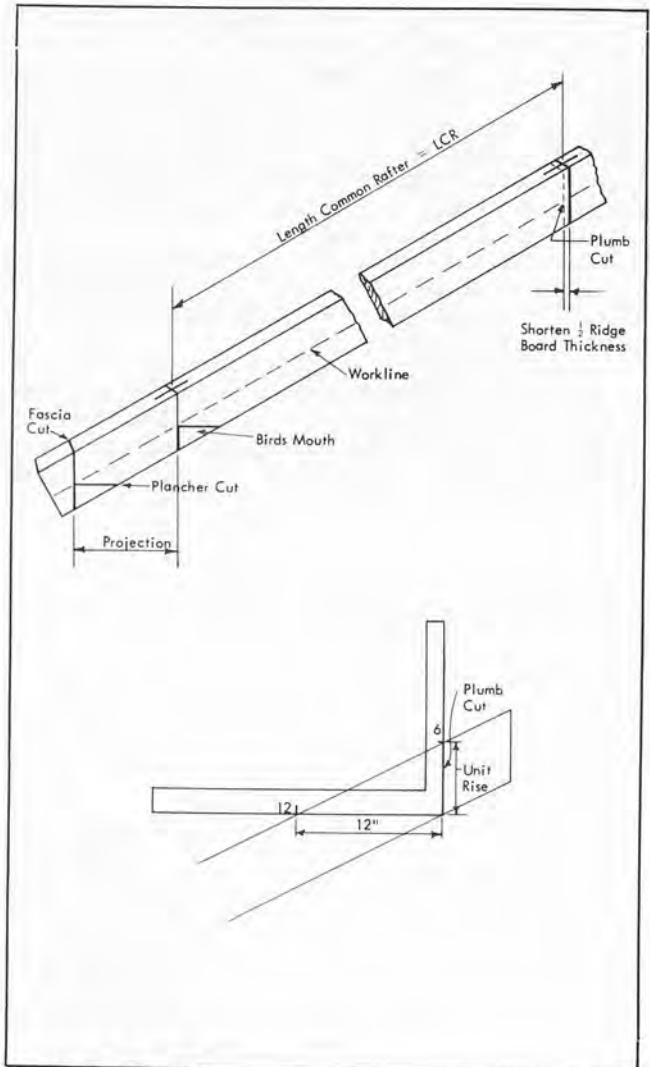


Fig 141-16. Rafter cuts.

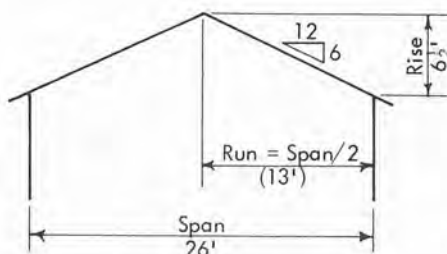
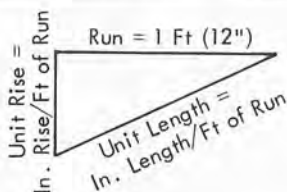


Fig 141-17. Example rafter calculations.

ASSUME: 26' Wide Building
FIND: Total Rise and Length
of a Common Rafter

1. Find Unit Rise

If $\frac{1}{4}$ Pitch is Given:
Unit Rise = Pitch $\times$ 24 (for any span)
 $= \frac{1}{4} \times 24 = 6''/\text{Ft of Run}$

If 6/12 Slope is Given:
(6/12 means 6" Rise per 12" Run)
Unit Rise = 6''/Ft of Run

2. Find Unit Length

$$\begin{aligned}\text{Unit Length} &= \sqrt{(\text{Unit Rise})^2 + (12'')^2} \\ &= \sqrt{6^2 + 12^2} = \sqrt{36 + 144} \\ &= \sqrt{180} = 13.42''/\text{Ft of Run}\end{aligned}$$

$$\begin{aligned}3. \text{ Rise} &= \text{Unit Rise} \times \text{Run} \\ &= 6''/\text{Ft} \times 13' = 6\frac{1}{2}'\end{aligned}$$

$$\begin{aligned}4. \text{ LCR} &= \text{Unit Length} \times \text{Run} \\ &= 13.42''/\text{Ft} \times 13' = 14'-6\frac{7}{16}''\end{aligned}$$

Truss Selection

Trusses are used in clear-span buildings. Trusses can be used with pole, stud, concrete block, etc. walls. Clear-span building construction provides for simple floor space arrangement. Halls, alleys, partitions, and equipment can be arranged, and rearranged, for best functional use of the space. There are no posts or bearing walls in the way. Machines and vehicles have maximum freedom of movement inside the building.

The bottom chords of trusses can support a ceiling. Head room clearance is restricted compared to rigid frame construction. Bird roosting may also be a problem.

Truss selection depends on:

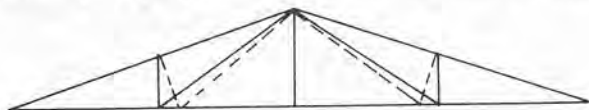
- web pattern
- span
- roof slope
- truss spacing
- dead loads
- snow zone
- lumber type

Web Pattern

Pratt web pattern truss designs are good for buildings with or without ceilings. The number of webs increases with heavier loads and longer spans for maximum use of chord lumber.

Increasing the number of webs increases the number of pieces of lumber and plywood required, but may decrease chord size.

For buildings without ceilings, the compression webs may be perpendicular to the top chord rather



than the bottom chord. The truss is not weakened if: top chord panel points are not moved, and web gussets are made a little wider to cover the same amount of each web member.

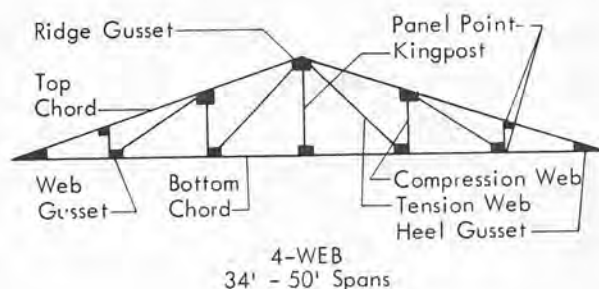
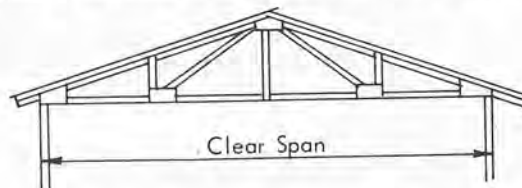


Fig 141-18. Truss parts.

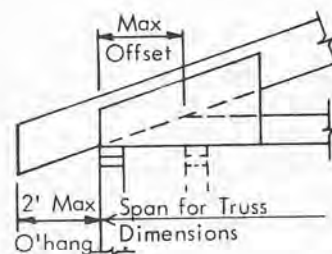
Span

Span is measured as in the sketch below.



Overhangs are limited to 2' because they cause increased bending in the top chord at the heel joint. If an overhang must exceed 2', use the top chord and heel gusset design for the next higher snow zone.

Trusses can extend beyond exterior walls, but not farther than the length of the bottom chord scarf cut.



Roof Slope

Roof slope significantly affects the forces in truss members. For a given span, spacing, and load, the member forces increase as the roof slope is decreased.

- 3/12 slope is commonly used in homes, commercial buildings, and some farm buildings in low snow load areas or for short spans and close spacings.
- 4/12 slope is the most common one used in farm buildings in all snow load areas.
- 5/12 slope affords a significant reduction of member forces over lower slopes for buildings in areas of high snow loads or for long spans and wide spacings.

Truss Spacing

Roof and ceiling materials, and wall framing, influence truss spacing selection. In pole buildings it is desirable to have each truss supported by a pole.

- 2' spacing uses more truss material and labor than wider spacings. It is common in short spans and low roof slopes for buildings with ceilings, solid roof decks, and shingles.
- 4' spacing supports many types of ceilings without special framing. It is common in insulated livestock buildings with metal roofs and in some machinery and equipment storage buildings.

- 8' spacing requires the least truss material and labor. It is common in buildings that require no ceilings: machinery and equipment storage, uninsulated livestock buildings, etc. Total cost may be greater if a ceiling is needed.

Dead Load - lb/sq ft (psf)

Dead loads include the weights of the roof, ceiling, trusses, braces, etc. Loads used by the MWPS are:

- Low, roof = 3.5 psf; ceiling = 0.0 psf.
- Medium, roof = 3.5 psf; ceiling = 5.0 psf.
- High, roof = 7.5 psf; ceiling = 8.0 psf.

Low dead load includes truss, purlins, metal roofing and minimum insulation weight (machine sheds or cold livestock buildings). Medium dead load allows for the addition of a metal or plywood ceiling with insulation (warm livestock buildings). High dead load allows for a plywood roof deck with asphalt shingles, and gypsum board ceiling with insulation (residential or commercial buildings).

Check the dead loads to be applied to the truss. Add the weights of the truss, purlins or decking, roofing, and roof insulation to get the dead load on the top chord. Add the weights of the ceiling and its supports, insulation supported by the ceiling, and any fixtures hung from the ceiling to get the dead load on the bottom chord. See the example below:

Example: Insulated livestock building.

Top chord dead load		
Truss weight—30' span, 4' spacing		1.5 psf
2x4 purlins—2' o.c.		0.7
28 ga steel roofing		0.9
	Total	3.1 psf
Bottom chord dead load		
1/2" plywood ceiling		1.4 psf
6" insulation		2.4
	Total	3.8 psf

Table 141-2. Weights of roofing and ceiling materials.

Roof framing	
2x4 purlins, 2' o.c.	0.7 psf
2x6 purlins, 2' o.c.	1.1
Ceiling framing	
1x3 furring, 16" o.c.	0.4 psf
2x4 furring, 2' o.c.	0.7
Sheathing, etc.	
1" lumber, solid	2.2 psf
3/8" plywood	1.1
1/2" plywood	1.4
0.024" aluminum	0.4
28 ga steel	0.9
Asphalt shingles	2.6
Insulation, per inch of thickness	0.1 - 0.4

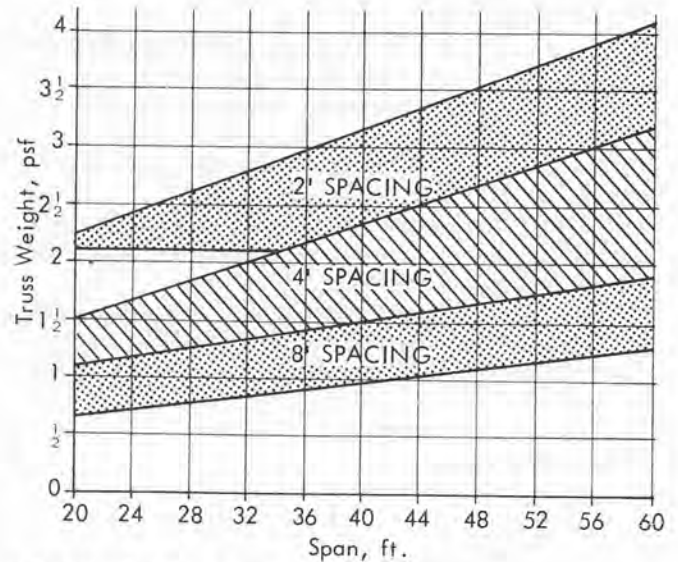


Fig 141-19. Weights of trusses.

Select the dead load case where the design loads exceed those expected or use the truss design for a greater snow load.

Snow Zone

Determine the snow zone number for your locality from the map below. If the building will be in mountain regions, consult local authorities and engineers for an adequate snow load.



Fig 141-20. Snow Zone Map.

ANSI A58.1-1972, 25 yr recurrence interval.

Design snow load, psf = Map load x 0.6

Zone I = 12 psf Zone III = 24 psf Zone V = 36 psf
Zone II = 18 psf Zone IV = 30 psf Zone VI = 42 psf

Table 141-3. Roof Loads, psf.

	Zone I			Zone II			Zone III		
	Low	Med	High	Low	Med	High	Low	Med	High
Snow Load (top chord)	12	12	12	18	18	18	24	24	24
Dead Load (top chord)	3.5	3.5	7.5	3.5	3.5	7.5	3.5	3.5	7.5
Dead Load (bottom chord)	0.0	5.0	8.0	0.0	5.0	8.0	0.0	5.0	8.0
Total (psf)	15.5	20.5	27.5	21.5	26.5	33.5	27.5	32.5	39.5

Table 141-4. Truss spacings for heavy snow zones.

Design Spacing	Zone:	Truss spacing		
		IV	V	VI
2'		1'-7"	1'-4"	1'-0"
4'		3'-3"	2'-9"	2'-1"
8'		6'-6"	5'-6"	4'-3"

Plywood

The plywood grade stamp, should specify C-C, 24/0 or 32/16, and Exterior (outer ply veneer grade, Identification Index, and type of glue, respectively). In addition, specify the plywood by the number of plies and thickness. If the design calls for 3/8", use 3-ply plywood with 24/0 Identification Index; if 1/2", use 5-ply plywood with 32/16 Index. An alternate 1/2" plywood is 4-ply if the grade stamp includes "Structural 1".

Tell your dealer that you want only plywood with **Group 1 wood species in the outer plies**. There are a few mills that produce the plywood specified with lower quality wood in the outer plies.

Do not use interior type plywood in either sanded or sheathing grades. Interior plywood with Exterior glue, CDX, may be used in buildings that will remain dry throughout their life, such as homes. Do not use CDX plywood in cold confinement buildings, etc., that will be exposed to high moisture conditions.

Lumber Type

Make trusses from lumber of a species and grade specified by the engineer.

Wind Loads

All MWPS trusses are designed to withstand winds of 80 miles per hour against a building in suburban areas, towns, city outskirts, wooded areas, and rolling terrain. Winds tend to lift the roof and roll the building over. In flat, open country, open flat coastal belts, and in areas having winds higher than 80 miles per hour, provide additional anchorage and bracing for the bottom chord and long diagonal webs.

Crane Loads

If crane loads are to be applied to the trusses, select a truss designed for the load. Consider where the load is applied and its duration.

Material

Lumber Quality

Lumber for trusses must be clean, smooth, and of uniformly good quality. Where members of different thicknesses (variations in manufacture) come together at a joint, sand or plane the thicker member so the gusset can make full contact. Top chord lumber should be full-length if possible.

Glue

The right glue to use:

Casein that is highly mold and water resistant,

though not water-proof, is adequate for most trusses. Use it for trusses which will stay dry through their life. Resorcinol resin is water-proof; use it for trusses with any joint exposed to unusual moisture conditions. Read the label carefully before you buy—make sure you're getting the right glue.

The right way to use it:

Follow the manufacturer's specifications for mixing, pot life (the length of time the glue stays good after mixing), temperature during use, etc.

Joints

Gussets

Apply a gusset to each side of each joint. **All web gussets may be made of 3/8" plywood.**

The heel gussets should cover at least the scarf cut, Fig 141-21. If the gusset is shorter than the scarf cut, either increase the length of the gusset or shorten the scarf cut by offsetting it. Radial arm saws typically have a maximum travel of approximately 24". If this is true for your saw, the scarf cut should be offset for large members to reduce its length and the heel gusset height increased, Fig 141-22. Some pole builders fix the truss heel depth for sliding door header framing and offset the scarf cut, Fig 141-23. The heel gusset should cover the top chord a minimum of 4", 6" when two layers of 1/2" plywood are used.

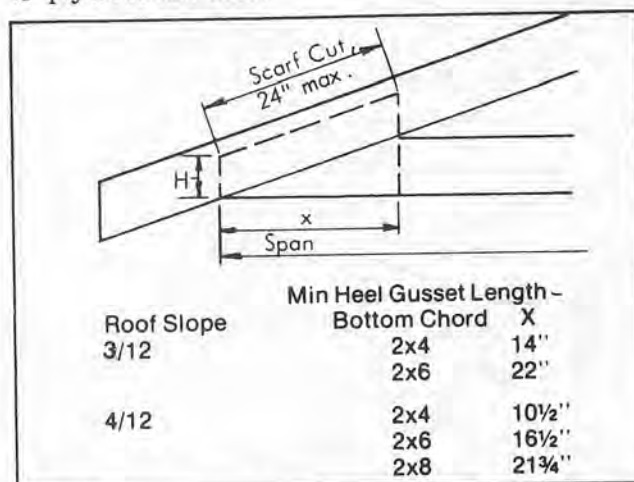


Fig 141-21. Minimum heel gusset length to cover scarf cut.

When the scarf cut is offset for any reason, increase the height (H) of the heel gusset by the amount of offset.

The web gussets should have at least a 4"x4" area for gluing 2x4 diagonal webs, 6"x6" for 2x6 webs. They should cover the top and bottom chords by 4" and the entire width of the vertical web. Minimum size is 8"x8" for 2x4 diagonal webs and 10"x10" for 2x6 webs. The minimum ridge gusset is 8"x12" for 2x4 diagonal webs and 8"x16" for 2x6 diagonal webs, with the height increased as the top chord size increases to cover it entirely.

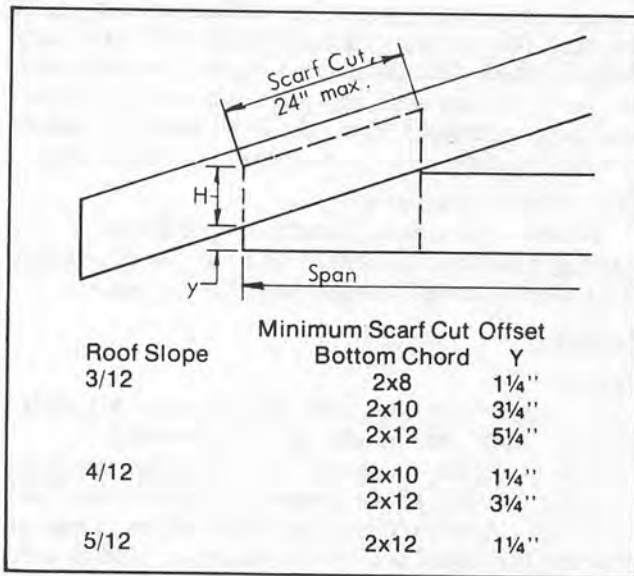


Fig 141-22. Minimum offset for 24" maximum scarf cut.

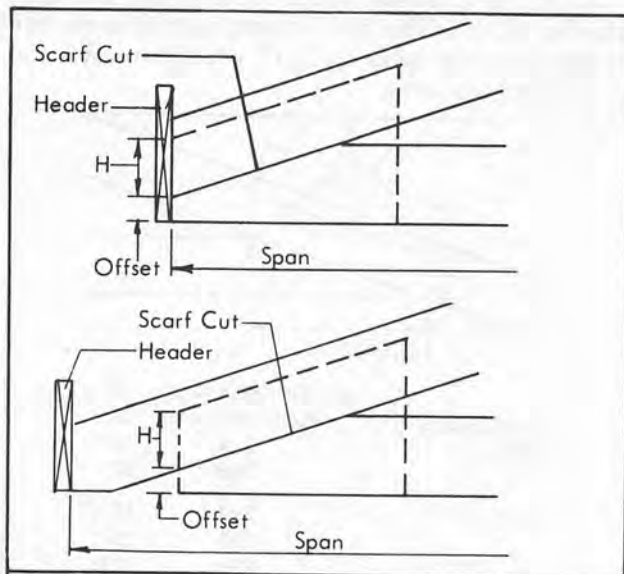
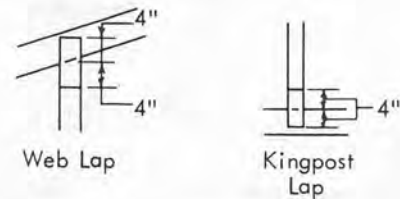


Fig 141-23. Scarf cut offsets used to fix truss heel depth for sliding door header framing in pole buildings.

When the scarf cut is offset for any reason, increase the height (H) of the heel gusset by the amount of offset.

Laps

Lap joints connect the shortest web to the top chord, and the king post to the bottom chord. Use 1" lumber or 1/2" plywood, as wide as the web or king post, glued and nailed to each side of each joint. Lap at least 4" over the web or king post and the chord.



Splices

Top chord and bottom chord lumber should be full-length if possible.

When splices are necessary, locate them as shown in Fig 141-24. Do not locate chord splices at the panel points, the combinations of forces from the chords and webs will overload the joints.

All splices: use 1" lumber the same width as the pieces to be joined. Glue-nail 16" lengths for 2x4's and 24" lengths for 2x6's and up, on both sides of the joint. For 2x4 splices 1/2" plywood (Identification Index 32/16) may be used instead of 1" lumber; for 2x6's and up use 3/4" plywood (Identification Index 48/24). Face grain must be parallel to the chord.

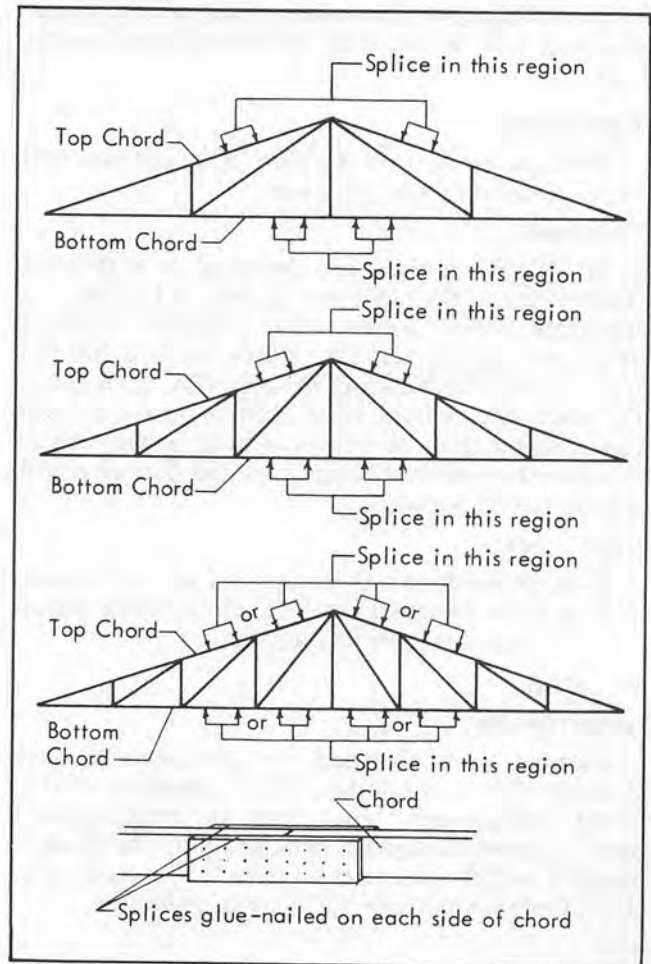


Fig 141-24. Splices.

Truss Construction

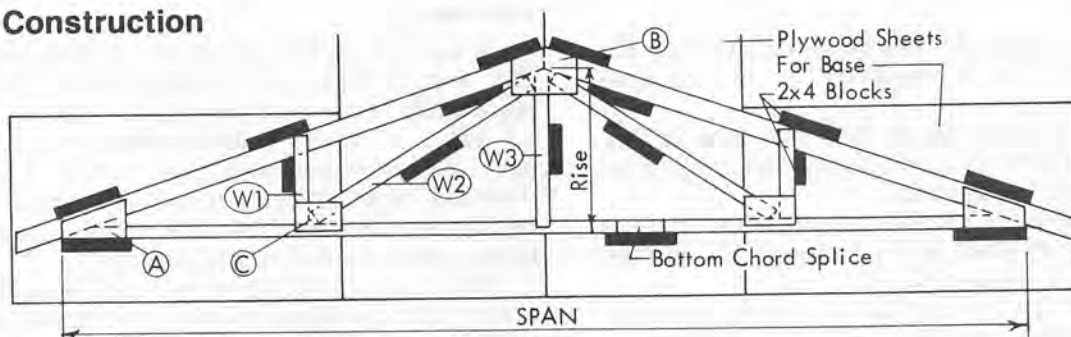


Fig 141-25. Truss jig.

Have the trusses made by an experienced truss builder if possible. If you build them yourself, learn how to make good glued joints.

Assemble One Truss

Select member sizes and lengths, and gussets required.

A "camber" or slight raising of the bottom chord at the center of the truss provides for settlement from dead loads without the truss appearing to sag. Provide about $\frac{1}{2}$ " rise for 40' trusses and 1" for 60' trusses.

Draw the complete truss on the floor or a plywood base. Cut lumber to fit. Lightly nail (**don't glue**) the complete truss together. Check the dimensions of the truss; both sides of the truss should be the same (rise, slope, position of joints).

Make a Jig and Cut Other Trusses

Nail 2x4 blocks to the base or floor around the lightly nailed truss. Mark off the 4" nail spacings along the jig at each joint.

Take the lightly nailed truss apart, and use its pieces as patterns for the rest of the trusses. Cut out the plywood gussets. The face grain of the heel gusset **must** be parallel to the bottom chord. The direction of the grain in the other gussets is not critical.

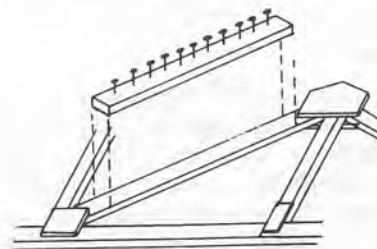
The king post may be omitted in trusses that will not have crossbracing attached, although a king post is recommended for all trusses supporting ceilings.

Gussets are required on **both** sides of each joint.

Double Webs

Buckling from forces created by snow loads or wind uplift is critical for web members in many large trusses—two 2x4's may be required to provide adequate stiffness.

Construct the truss with single web members, then cut an additional 2x4 to fit between the gussets. Nail it securely with 10d nails about 6" apart.



In even larger trusses, both buckling due to wind uplift and tension due to snow loads are critical—a 2x6 and a 2x4 may be required. The 2x6 is required for tension and should be glued into the truss as the primary web member and the 2x4 added as a double web to provide adequate stiffness. The 2x4's used as double webs are stiffeners and do not need to be of high quality.

Assemble and Glue

Use the jig to make uniform trusses.

Use plenty of glue—it's the cheapest part of the building. Spread the glue with a fiber glue brush or paint roller.

Apply to both surfaces to be joined. When you nail the gussets in place, glue should ooze out from around the joint—if it doesn't you're not putting on enough glue.

Use 5d or 6d box nails, preferably galvanized or cement coated. Space rows of nails 2" apart across the lumber grain. Nail 4" apart with the lumber grain, starting with a middle row, and nailing outward to the edges of the lumber. Follow machine nailing or stapling with a hammer if glue isn't oozing out.

Raise the peak of the truss and turn the truss over, out of the jig.

Glue and nail the gussets on this side, and nail on the double webs if required.

To eliminate errors in the pattern, which may result in an uneven ridge, mark one end—e.g. right end—of each truss and erect the trusses with that end on the same side of the building.

Move the truss out of the way and store flat for at least 24 hours. After the glue has cured, the truss is ready to be placed on the structure.

Precautions

Remove all dirt, oil, and sand from the lumber and plywood. This is necessary for a good glue bond.

Protect the glued joints from moisture for one week after fabrication. A plastic covering over stacked trusses is adequate.

Temperatures below 70° delay curing. Trusses will be ready to erect in 24 hours at 70°, but require at least a week at 40°.

Above 85°, pot life may be very short. Keep the glue in the shade, and close and nail joints as soon as possible after spreading. Consider keeping the pail of mixed glue in a bucket of ice in hot weather.

Endwall Trusses

Endwall trusses are sometimes built without gussets on the outside face to simplify application of endwall siding. However, the endwall truss is not strong enough to support additional building length in any future expansion. If you might lengthen the building someday, put gusset plates on both sides of the joints and space plywood scraps along the truss members for siding application.

Truss Erection

A building must be adequate to withstand the snow and wind loads that come after the building is complete.

The building walls support the trusses and anchor them against wind loads. Girders or lintels over opening should be strong enough to hold the trusses without excessive deflection. Consult an engineered plan for adequate design of the girder and its fastening.

Placing

Lighter trusses can be lifted by hand and placed on the walls upside down. Lift heavier trusses into place with a hoist. The trusses are positioned, anchored, and braced one at a time.

Windbracing

Brace and anchor the trusses as they are placed. The bracing helps align and hold the trusses in place while the roof and ceiling are applied.

Install stiffeners along the bottom chords at all panel points (where webs meet bottom chord) continuously from endwall to endwall unless a rigid ceiling is to be installed. The cross-bracing on the king posts is needed in all buildings.

Install cross-bracing for at least 16' at each end of the building. Space additional 16' braced sections not further than 32' apart.

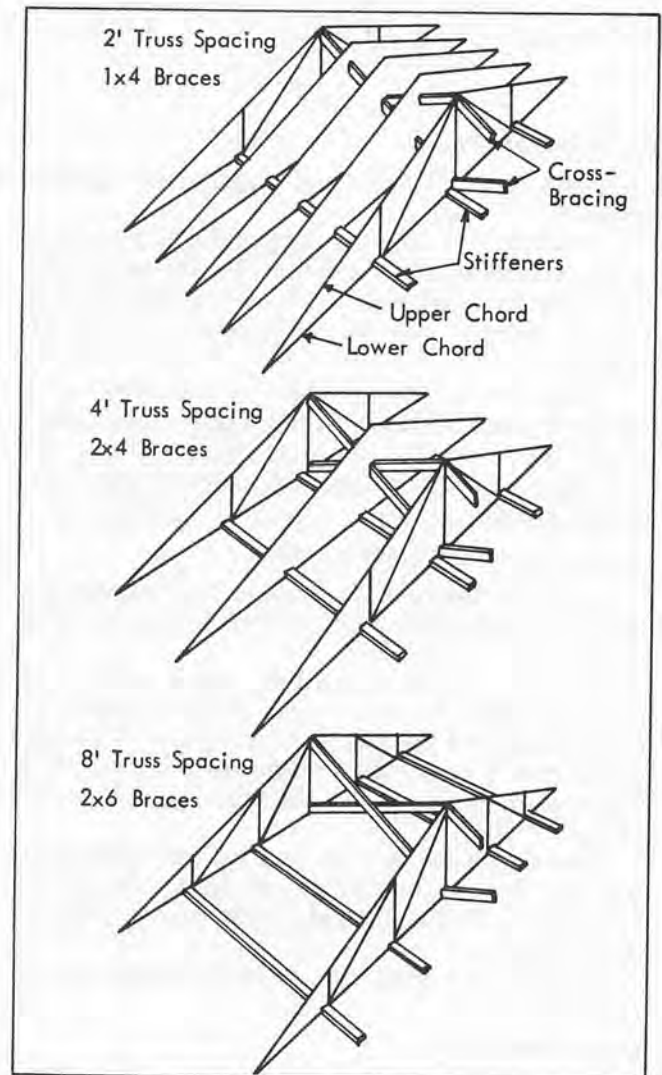
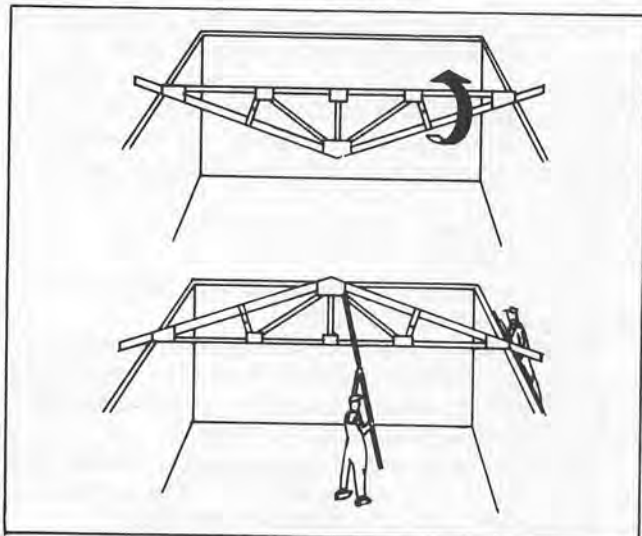


Fig 141-26. Windbracing.

King posts may be omitted on trusses that do not support crossbracing. A king post is recommended for all trusses supporting even light ceilings to aid in nailing to the center section of the bottom chord.



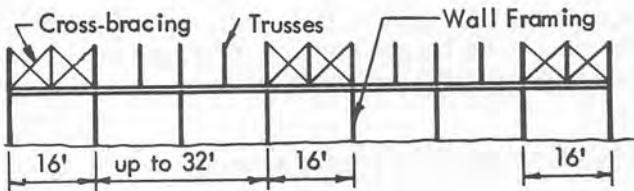


Fig 141-27. Cross-bracing.

Wind Anchorage

The wall holds the truss up. Anchorage resists uplift on a roof due to the wind.

Table 141-5. Minimum fasteners for wind anchorage, both ends of each truss.

Truss Span	Truss Spacing		
	2'	4'	8'
20' - 24'	1A or 1B	1A or 1B	2A or 1B
26' - 30'	1A or 1B	1A or 1B	2A or 2B
32' - 46'	1A or 1B	2A or 1B	3A or 2B
48' - 50'	1A or 1B	2A or 1B	4A or 2B
52' - 60'	1A or 1B	2A or 2B	4A or 3B

A = Framing Anchor

4-30d ringshank nails equal one 1/2" bolt.

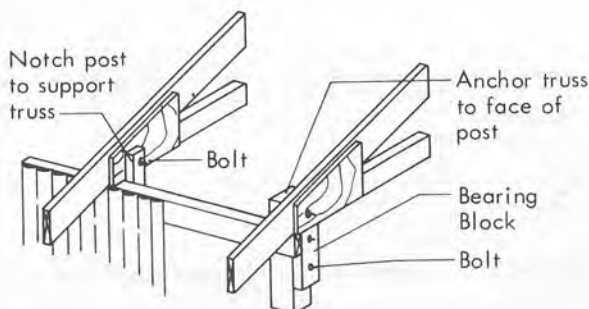
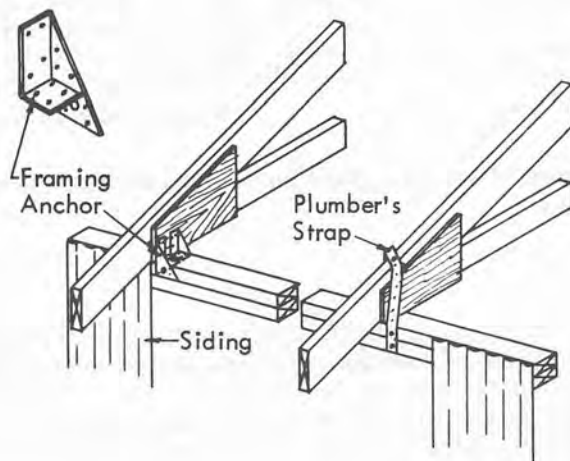


Fig 141-28. Truss anchorage.

Use the following attachment method in post and girder walls for trusses placed between the posts.

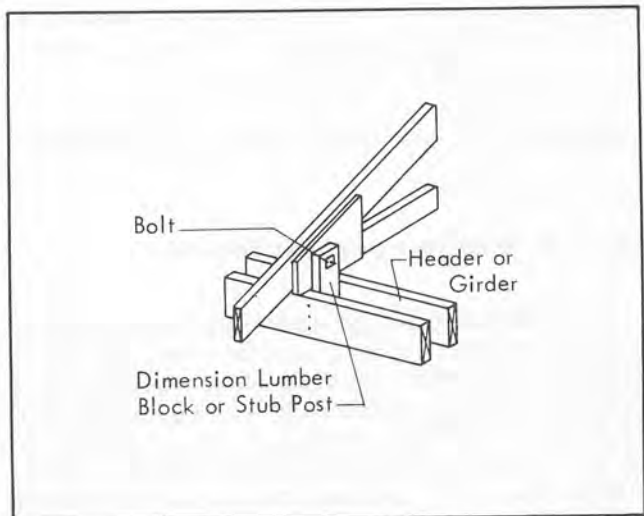


Fig 141-29. Truss to girder anchorage.

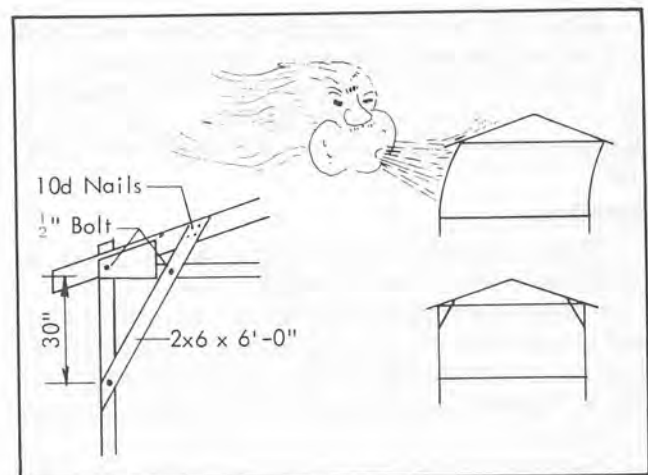


Fig 141-30. Typical knee brace—8' o.c.

Knee Bracing

In stud wall construction, knee braces stiffen the wall and roof joint to resist high winds. In buildings with rigid cross-partitions, such as homes, knee bracing is not required. In pole buildings with poles sized assuming rigid pole-to-truss joints, the knee-brace is part of the structural system. Knee bracing may be omitted in pole buildings with poles sized assuming pinned pole-to-truss joints.

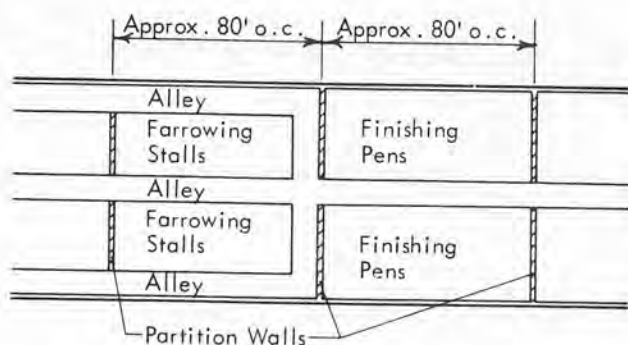


Fig 141-31. Windbracing with partition walls.

In stud wall buildings where knee braces are not wanted, partition walls can be used for wind bracing. Brace walls approximately every 80' by a partition wall of a structurally sound skin material: preferably plywood; possibly metal roofing or cement asbestos board; not insulation or fiber board. Anchor the wall to the floor and to the bottom chord of a truss in a manner similar to that of an endwall. Some small doors will not seriously reduce the partition's stiffness.

Roof and Ceiling Construction

Roof Construction

After the trusses have been placed, anchored, and braced, the roof and ceiling can be applied.

Select the type of roofing and ceiling material to be used. Framing and sheathing required depends on the roofing material and the truss spacing.

Sheathing

Many types of material can be used as sheathing. Plywood is common.

Anchor sheathing $\frac{1}{2}$ " or less thick with 6d nails and thicker sheathing with 8d nails. Space nails 6" apart along panel edges; 12" apart along other supports. If panel supports are 48" o.c., space all nails 6" apart.

For support spacings of 32" or more, use T&G plywood, blocking under joints, or plyclips on panel edges between supports.

Plywood may expand a little; leave $\frac{1}{16}$ " space between roof or wall panel ends and $\frac{1}{8}$ " between sides to allow for possible expansion.

Support 1" lumber sheathing 24" o.c., 48" o.c., if it is T&G, in both farm and residential construction. Anchor with 8d nails. Space supports for rolled steel and aluminum roofing according to manufacturer's recommendations.

Roof Purlins

The maximum spacing between roof purlins depends on the sheathing or roofing materials used,

and on the strength of the purlin itself. For maximum spacing between purlins, based on snow load and truss spacing, see Table 141-6.

Table 141-6. Maximum support spacing.

Roof Purlin Size	Truss Spacing	Snow Zone			Residential
		I	II	III	
1x3	2	40"	29"	24"	16"
2x4 flat	4	61"	44"	35"	24"
2x4 on edge	8	32"	24"	20"	

(Reduce spacing as required by roofing material)

Stagger purlin joints for continuity across the trusses. Purlins may be laid flat with 2' and 4' truss spacings. Butt joints may be used over a truss and 8', 12', or 16' lengths used.

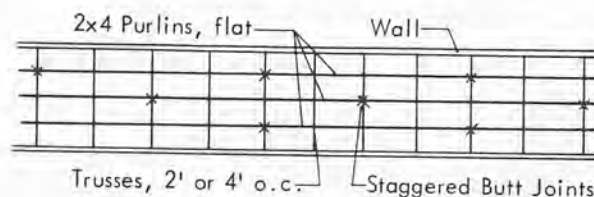


Figure 141-32. Staggered purlin joints for trusses, 2' or 4' o.c.

Alternating purlin lengths may be used in pole buildings where the poles are spaced evenly and the trusses are not. For poles 8' o.c. they may be of alternating 16' and 18' lengths with staggered lap joints if pairs of trusses are mounted on alternate sides of the poles.

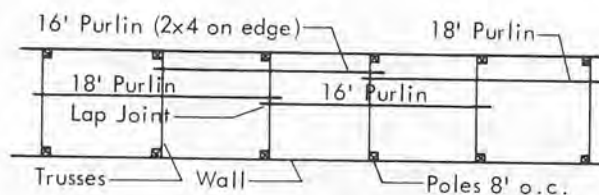


Fig 141-33. Staggered purlin joints for trusses, 8' o.c.

Installation of knee braces at sliding door and vent door locations may dictate altering this pattern.

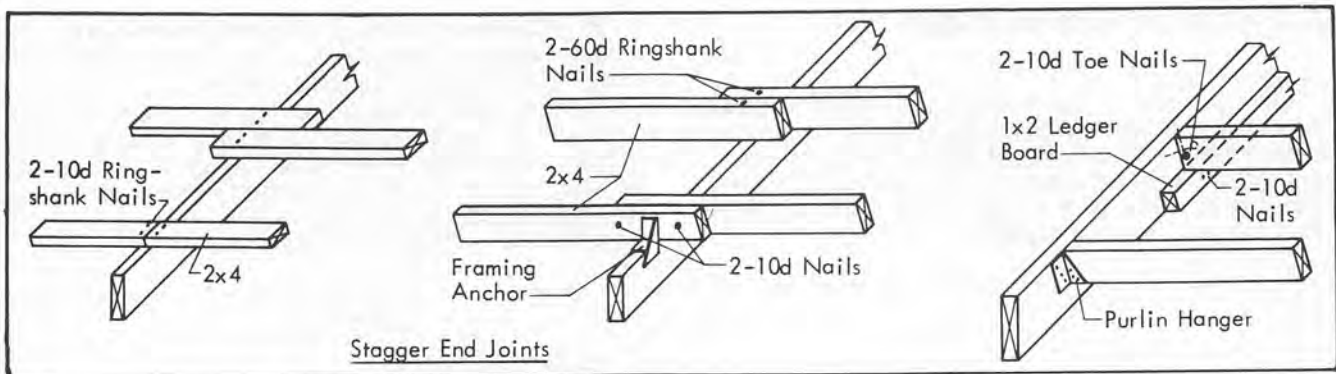


Fig 141-34. Roof purlin anchorage.

Ceiling

Examples are given below for plywood ceilings. Rolled steel or aluminum roofing with the ribs running across the supports (as shown for plywood face grain) is about equivalent to $\frac{1}{2}$ " plywood. These can support insulation above. Follow manufacturer's recommendations.

Leave spaces, $\frac{1}{16}$ " on ends and $\frac{1}{8}$ " on sides, between plywood sheets in ceilings of high-humidity buildings, such as livestock housing, to prevent possible buckling from moisture expansion. Paint (exterior oil base) the edges of plywood sheets before installing them to prevent moisture movement into them thru the edges.

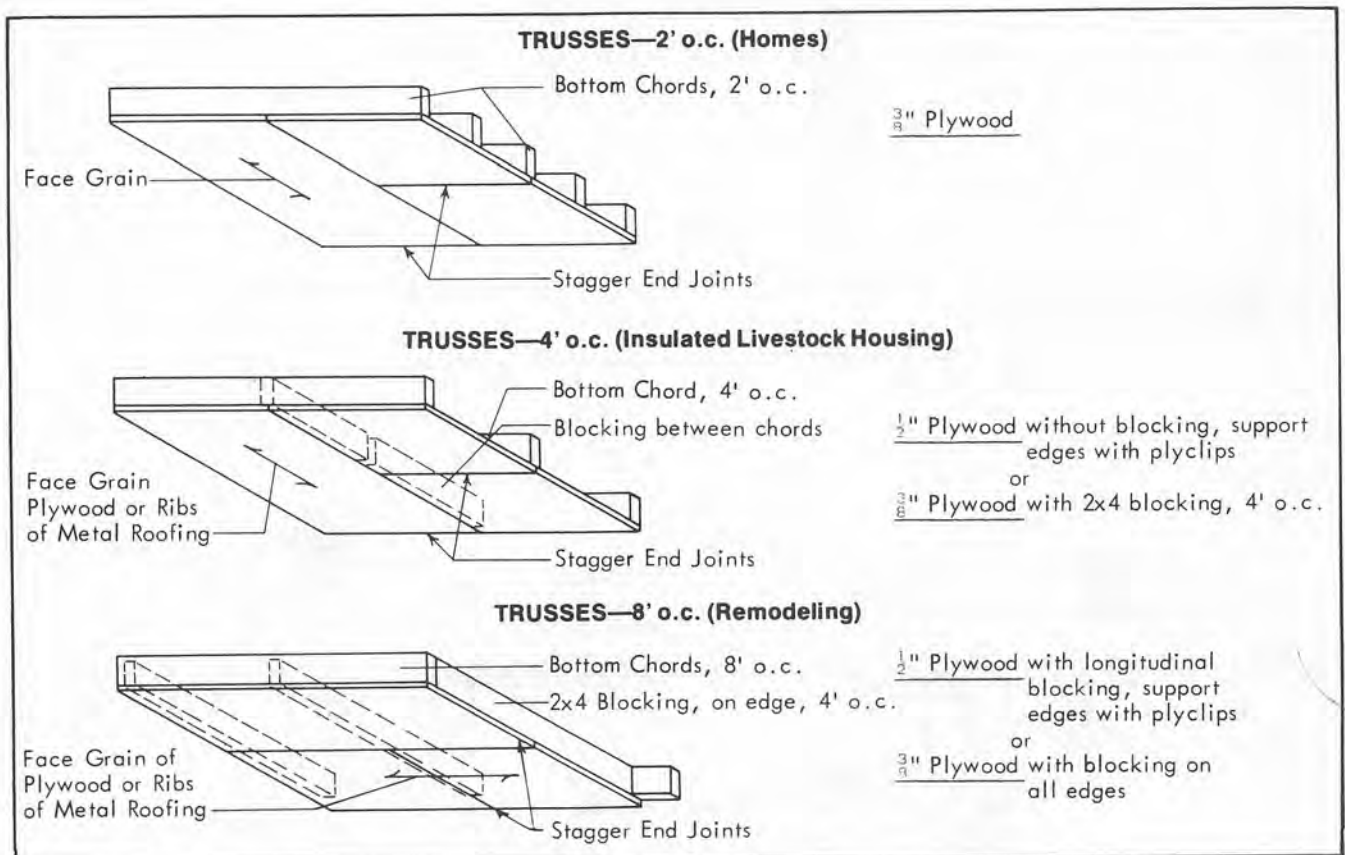


Fig 141-35. Ceiling construction.

POLE-TYPE CONSTRUCTION

Pole-type frame construction uses treated round timber poles or sawn timber posts set in the ground as the main structural members. Girts, purlins, and rafters are attached to the poles to form a complete building frame. The poles serve as foundation, studs, and roof support.

Pole framing adapts to home construction as well as farm building construction. Girders attached to the poles above ground level can support joists, subflooring, and finished flooring over a crawl space.

Poles set to moderate depths in average soils support buildings safely even against high winds or heavy snow load. The structure can be designed so that all of the bracing of the building may be taken by the pole at the ground line.

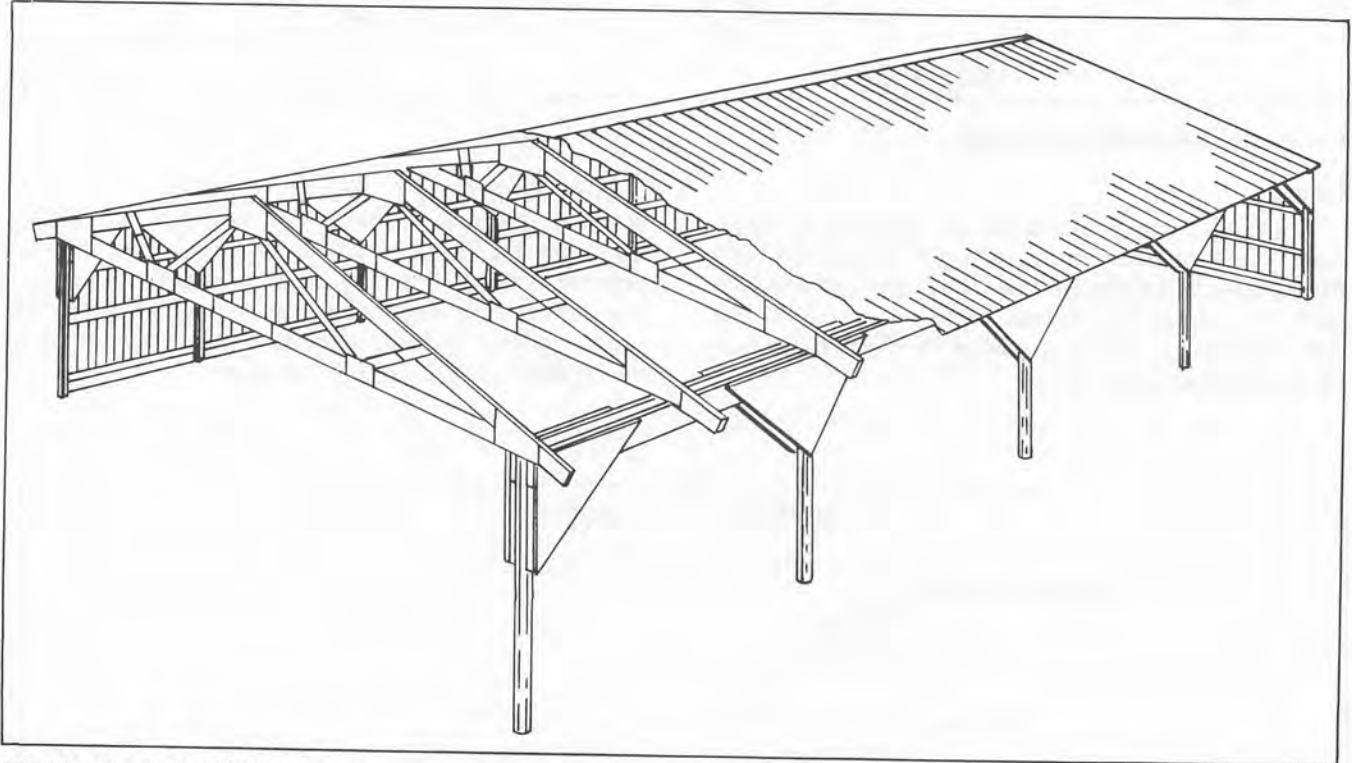


Fig 141-36. Pole utility building.

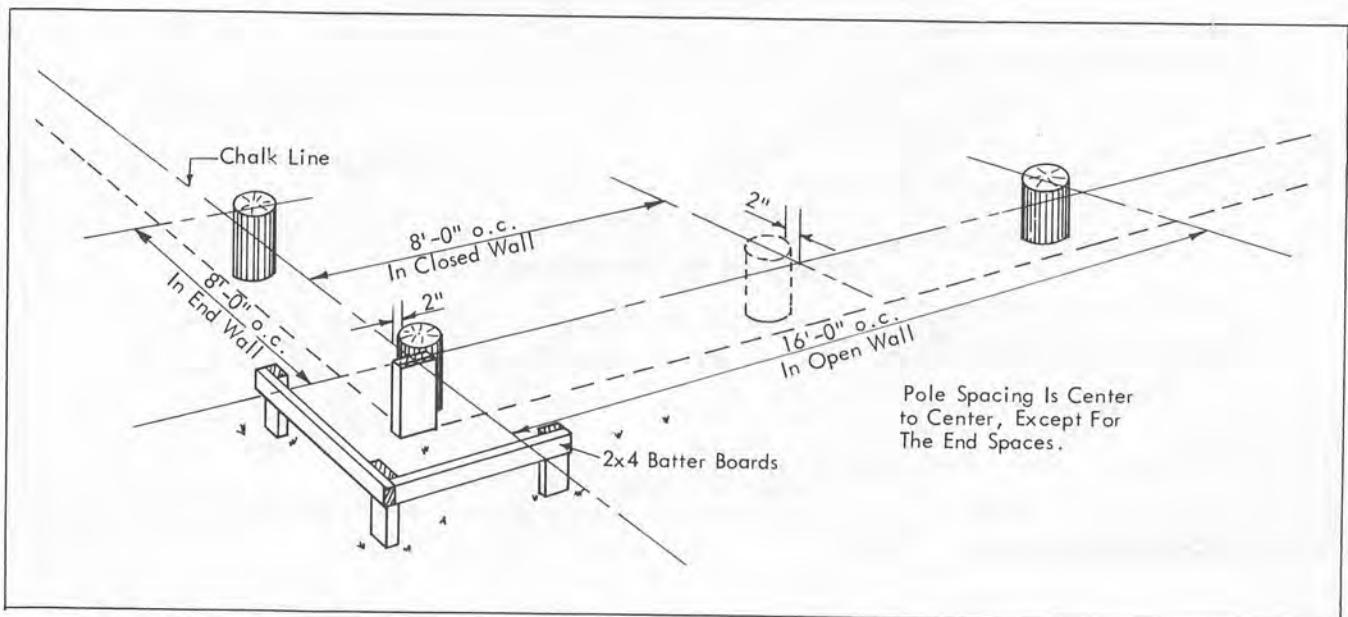


Fig 141-37. Pole spacing detail.

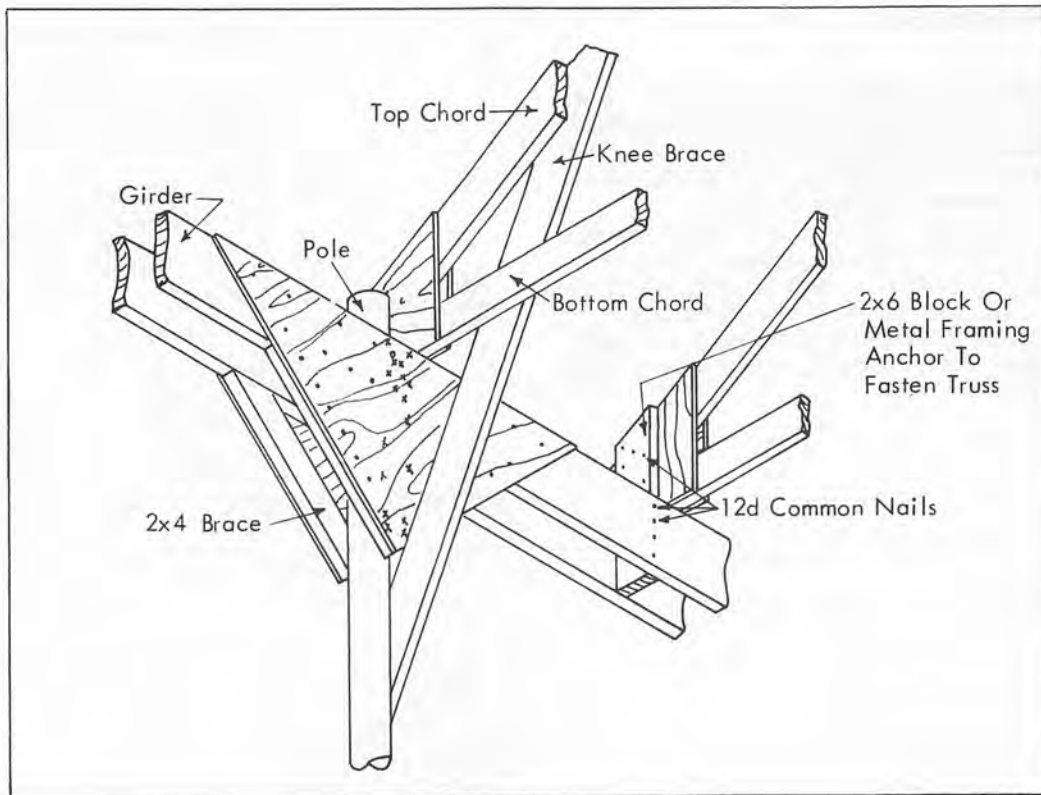


Fig 141-38. Pole detail.

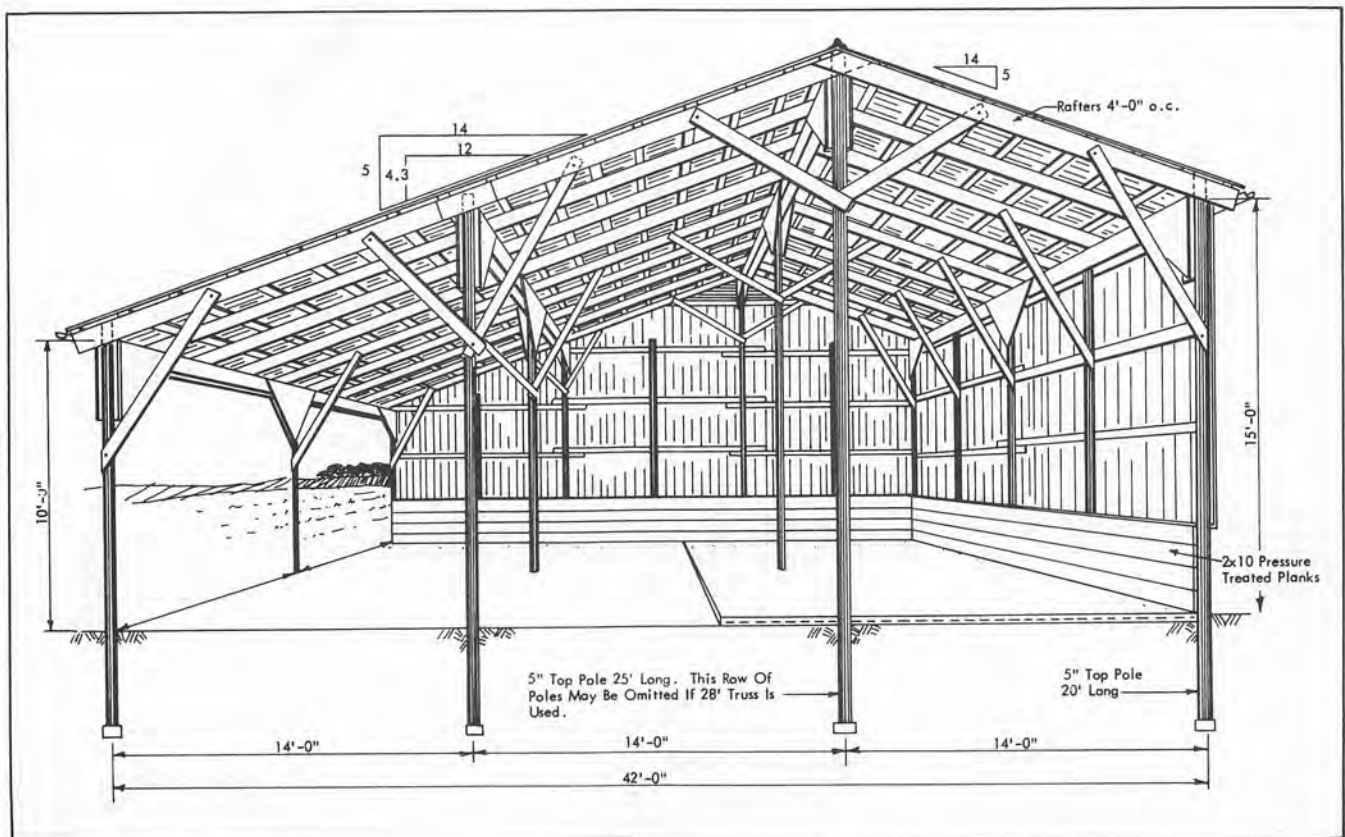


Fig 141-39. Pole building with interior poles.

ARCHED RAFTERS

Wood arched rafters have been used for most kinds of farm production and storage buildings. Glued laminated bent rafters are commonly fabricated in factories while sawed (vertical laminated) rafters can be assembled on a job site.

Relatively complex framing is needed to put doors in the sides of these structures. Doors can be conveniently installed in the endwall. Ceilings may be installed, but many of the advantages of this framing system are lost if ceilings are used. Arched buildings are especially useful where high ceilings are needed.

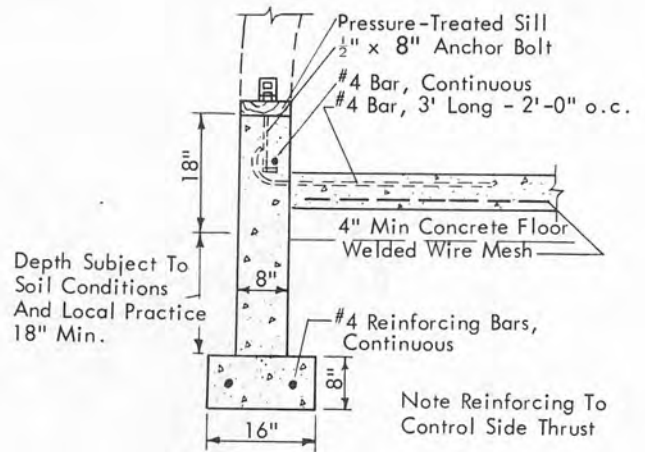


Fig 141-40. Floor detail.

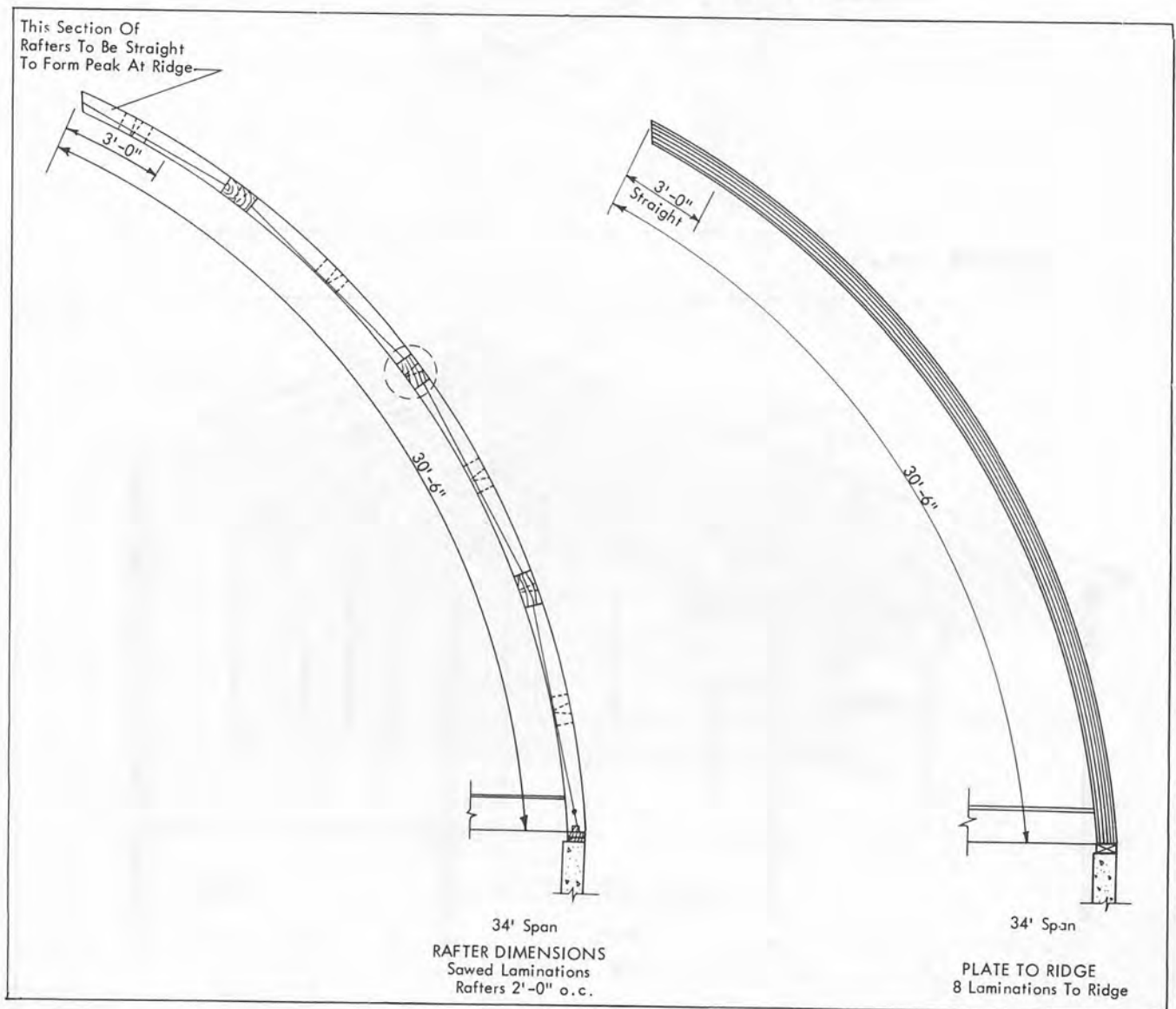


Fig 141-41. Laminated arches.

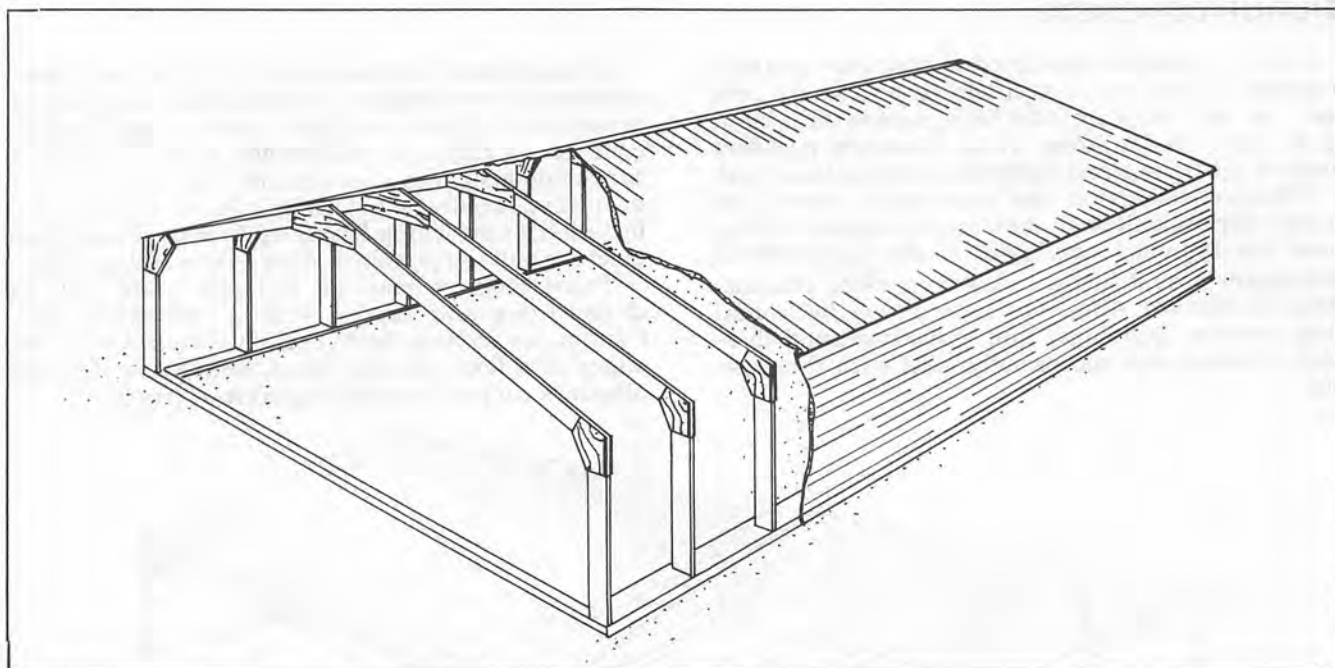


Fig 141-42. Rigid frame utility building.

RIGID FRAMES

With this system two studs and two rafters are combined to form a structural unit with a gable shape similar to arched rafters. Plywood gussets are nailed and glued on each side of the eave joints and the ridge joint to form rigid frames.

Rigid frames form a structure completely free of interior obstructions, and therefore are well suited for many types of farm buildings. Construction is simple since individual frames consist of a relatively small number of different sizes and shapes of framing members. The cost is no greater than for other systems of clear-span construction and may be less.

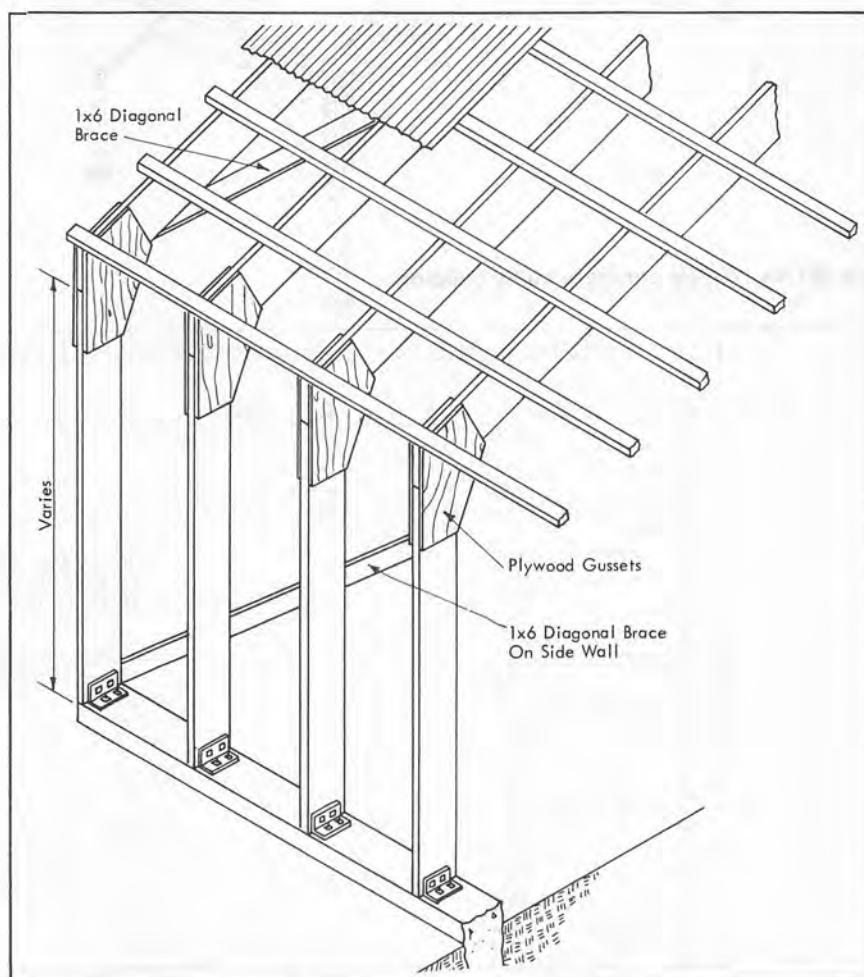


Fig 141-43. Framing detail.

TILT-UP CONCRETE

Tilt-up concrete construction involves casting concrete panels on a sand bed or previously cast floor at the building site. The panels are tilted up to form the building walls. Concrete pilasters connect the panels and make the construction rigid.

Tilt-up construction has been highly developed in commercial buildings, but requires heavy equipment not typically available on the farm. Newer techniques permit tilt-up on the farm using common farm equipment. Above- or below-grade horizontal silos, service buildings, and even insulated livestock shelters are successfully built with this system.

A sand bed covered with 4 mil polyethylene sheeting is a satisfactory casting bed. Panel forms are commonly 2x4 and 2x6 lumber. High quality concrete is required. Reinforcing steel is designed to provide adequate strength and stability and must be placed accurately. Tilting bolts or anchors are installed for attaching lifting equipment. Wheel-type tractors pull the panels upright with a tilting frame.

Panel footings may be concrete piers cast in drilled holes and capped with a rectangular pad. Continuous footings and specially formed thickened edges of a floor are also used. Reinforced concrete pilasters support the walls against overturn.

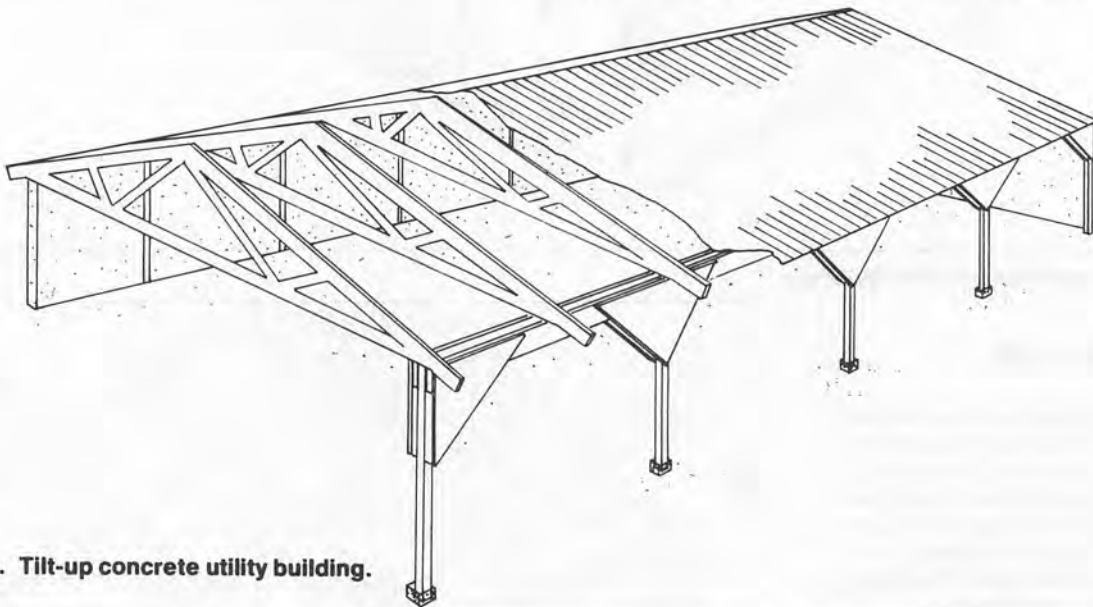


Fig 141-44. Tilt-up concrete utility building.

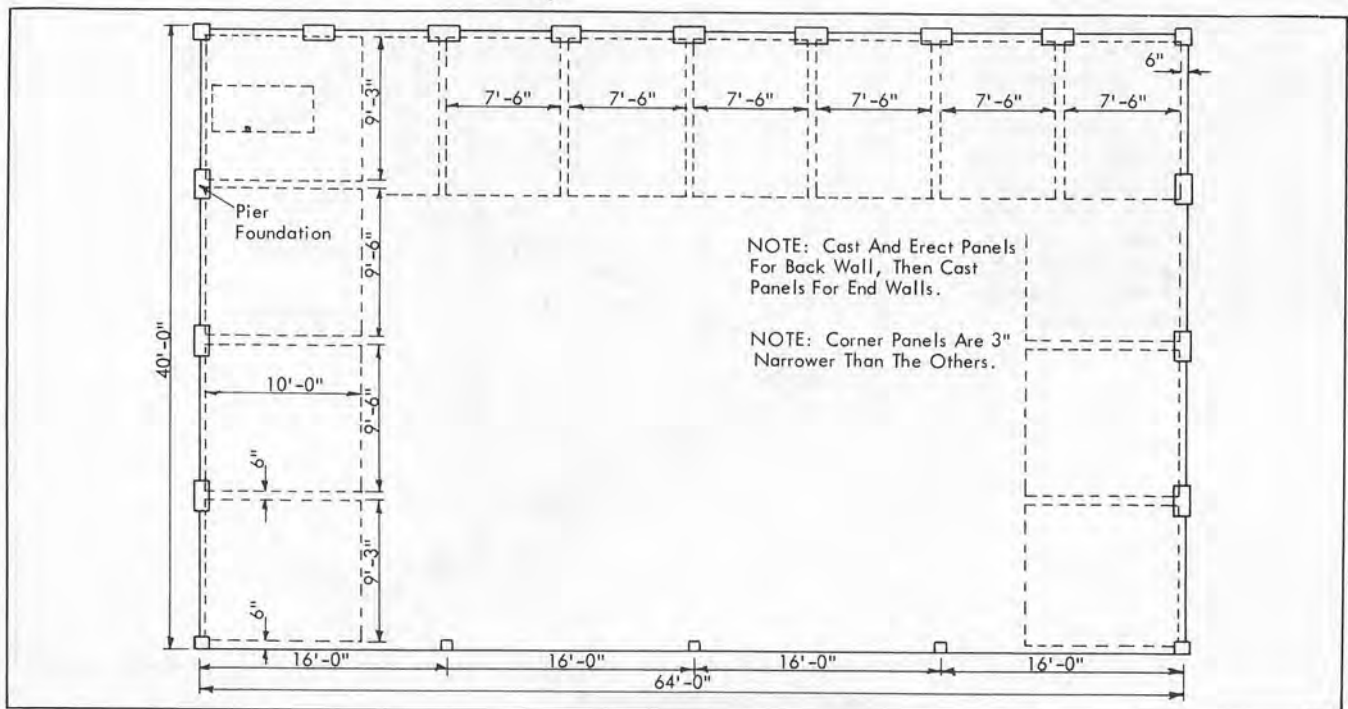


Fig 141-45. Floor plan.

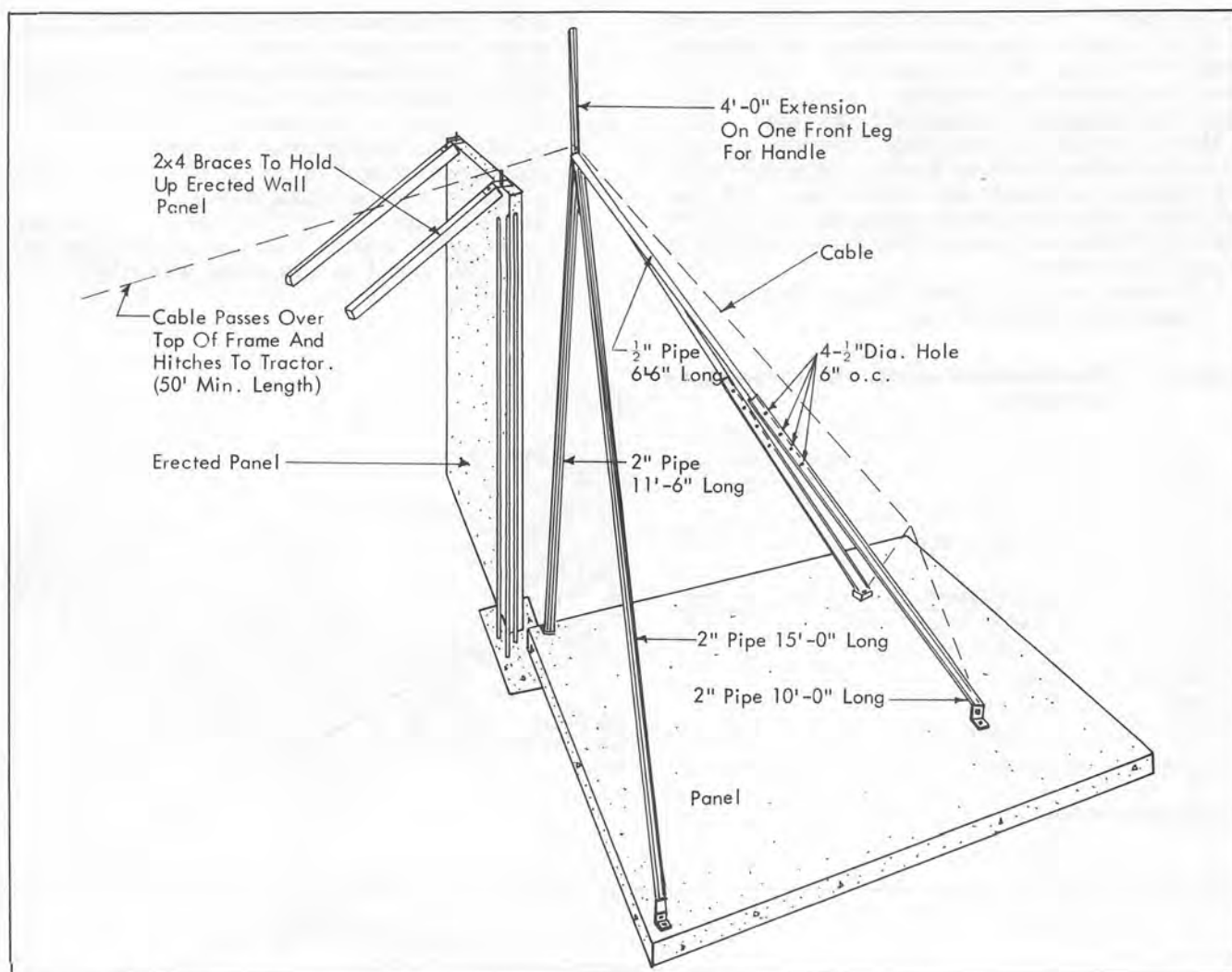


Fig 141-46. Tilting frame.

CONCRETE MASONRY

Concrete masonry is available in heavyweight and lightweight units. Blocks made with Portland cement, water, and normal aggregates weigh 40 to 50 lbs. Lightweight units are made of Portland cement, water, and lightweight aggregates, such as cinders, expanded clay, or slag. A typical lightweight unit weighs 25 to 35 lbs. Lightweight units are easier to handle and have about 50% greater insulating value, but are not as strong as the heavier units.

Concrete blocks are manufactured in 4", 6", 8", 10", and 12" widths. They also come in shapes adaptable to almost any masonry need.

The most common unit is the stretcher block, 8" x 8" x 16" (nominal size) that is really 7 5/8" x 7 5/8" x 15 5/8". When laid in courses with 3/8" mortar joints it makes a wall section 8" high and about 8" thick.

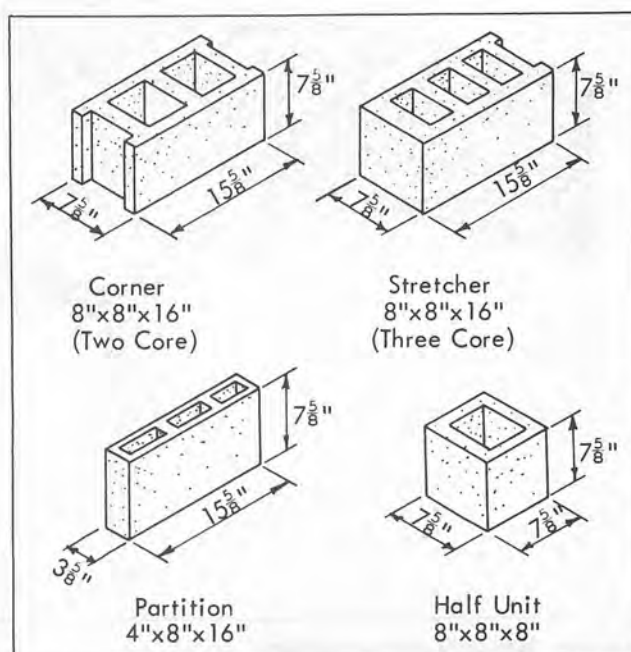


Fig 141-47. Common concrete block.

The mortar mixes shown in the table can be used in repairing and tuckpointing old masonry walls as well as for new masonry construction. After the mortar has partially stiffened, the joints should be thoroughly compacted by tooling.

Mortar should be used within two and one-half hours after original mixing when the air temperature is 80 degrees or higher and within three and one-half hours when the air temperature is below 80 degrees. Mortar not used within these time limits should be discarded.

1. Corners are built first, four or five courses higher than center of wall.

2. After laying each corner course, check alignment for level and plumb.
3. Use a 1 x 2 board with markings eight inches apart to locate top of masonry for each course.
4. Use a mason's line stretched from corner to corner to insure horizontal accuracy.
5. Blocks are brought to proper grade and made plumb by tapping with a trowel handle.
6. Run a round "O" or "V" shaped tool along joints after mortar has somewhat stiffened. This will assist in providing watertight construction.

Table 141-7. Recommended mortar mixes proportions by volume.

Type of Service	Cement	Hydrated lime	Mortar sand in damp, loose condition
For ordinary service	1—masonry cement ^a	--	2¼ to 3
	or		
Subject to extremely heavy loads violent winds, earthquakes or frost action.	1—portland cement	½ to 1¼	4½ to 6
	1—masonry cement ^a	--	4½ to 6
	plus 1—portland cement		
	or		
	1—portland cement	0 to ¼	2¼ to 3

^aASTM Specification C 91 Type II.

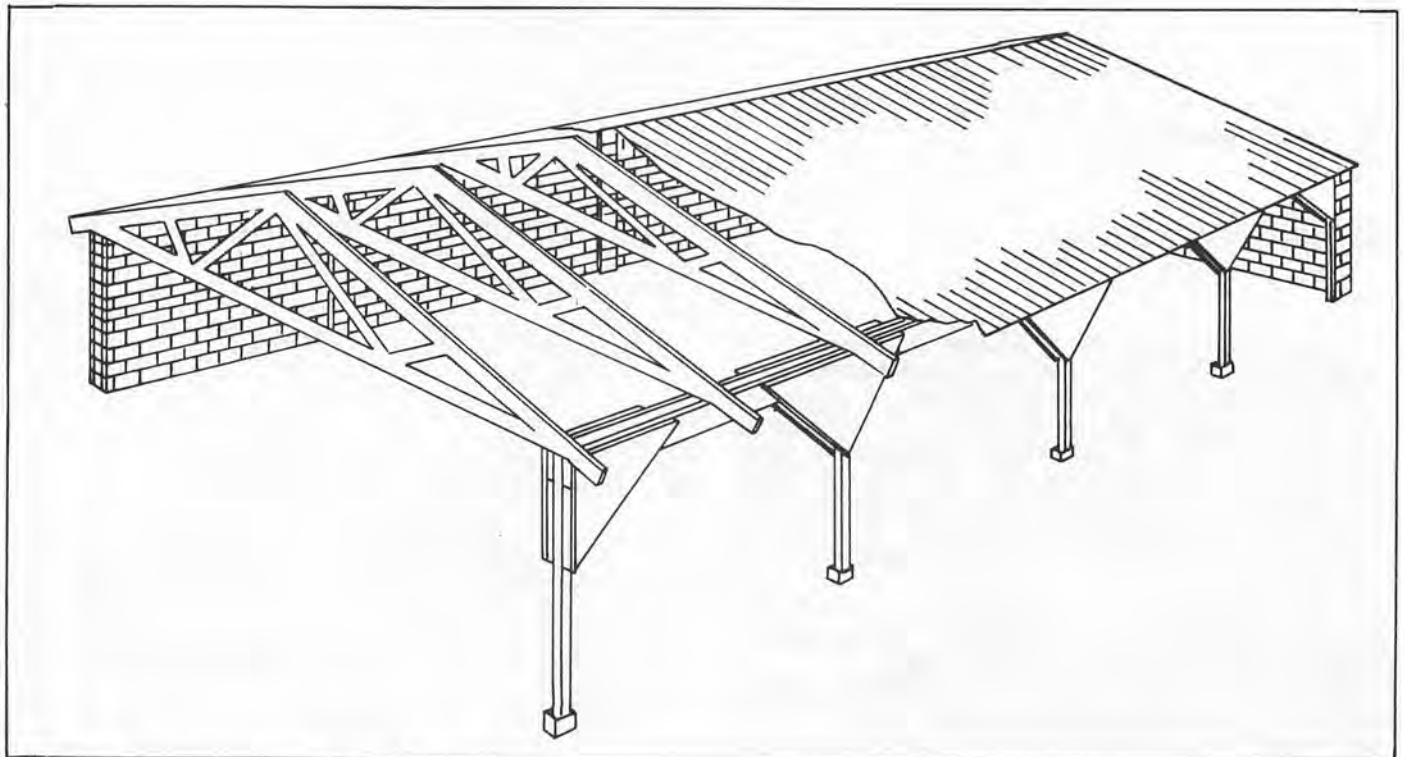
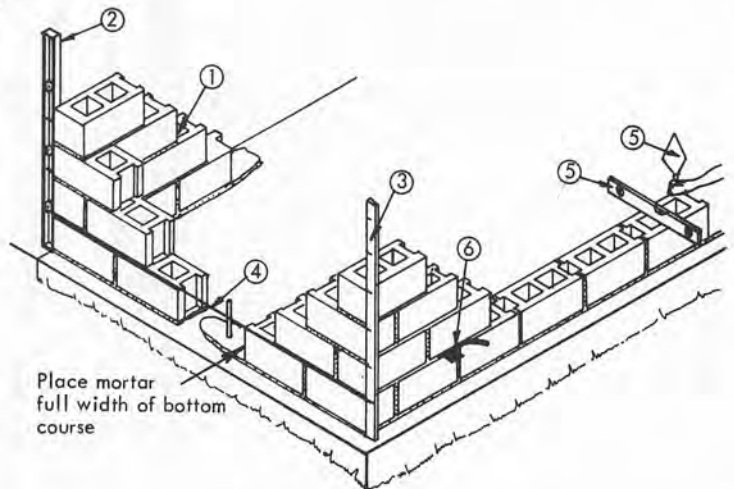


Fig 141-48. Masonry utility building.

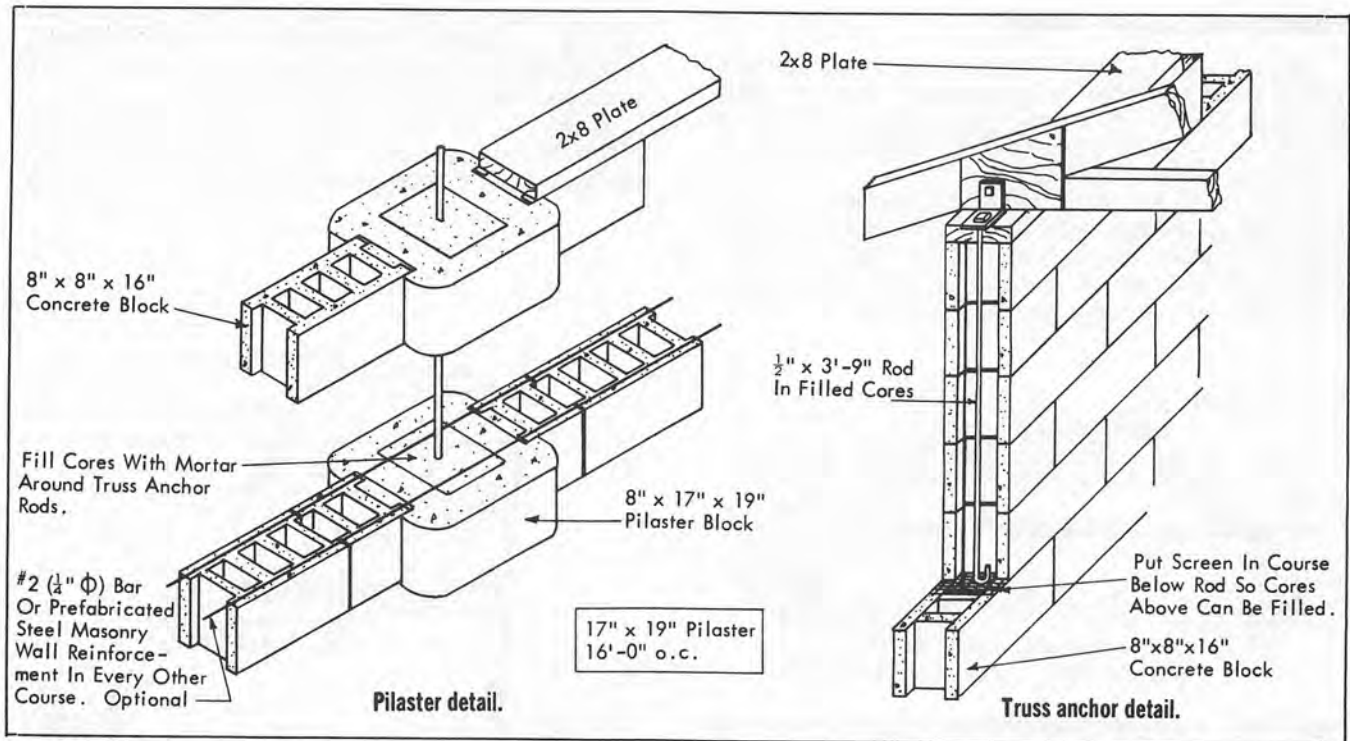


Fig 141-49. Masonry details.

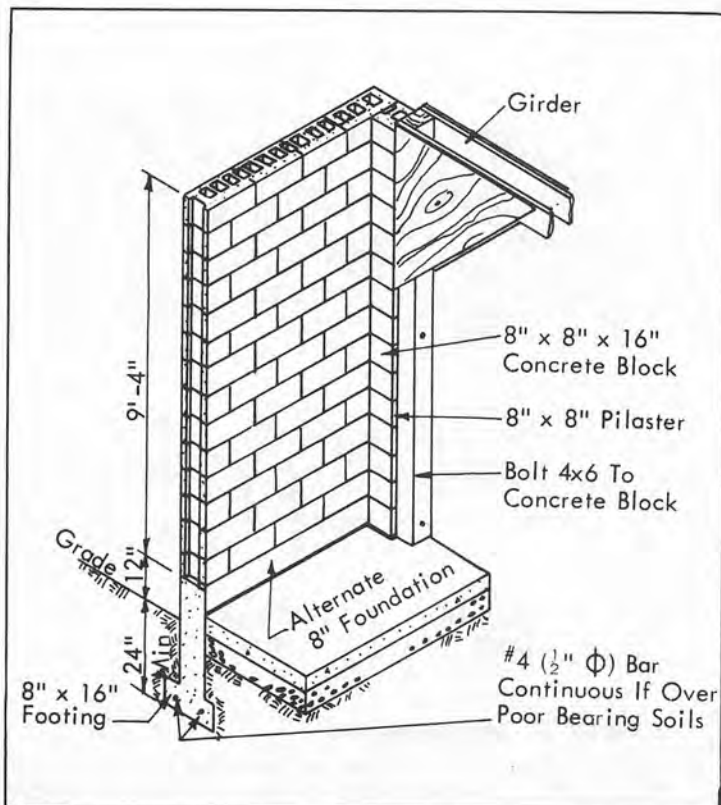


Fig 141-50. Corner detail and alternate foundation.

Pavement Construction

Remove all sod and vegetable matter. The subgrade must provide uniform support and be easily drained. The top 6" of subgrade should be of sand, gravel or crushed stone where subgrades may be water soaked much of the time.

Use 6 x 6 #10 wire mesh in pavements poured over soft or spongy soils. In general, place the wire about 1" from the bottom of the slab. Place the wire near the top of slabs that will support light loads but are subject to frost heaving.

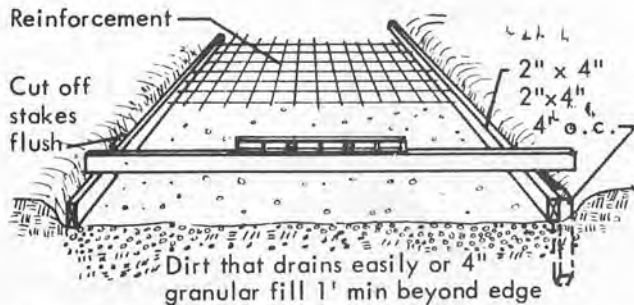


Fig 141-51. Preparing subgrades and laying reinforcing if needed.

Thoroughly dampen the subgrade before concrete is placed. Place the concrete near where it will be used to help prevent scaling and dusting from too much handling. Spade or vibrate along the forms to eliminate voids or honeycombs.

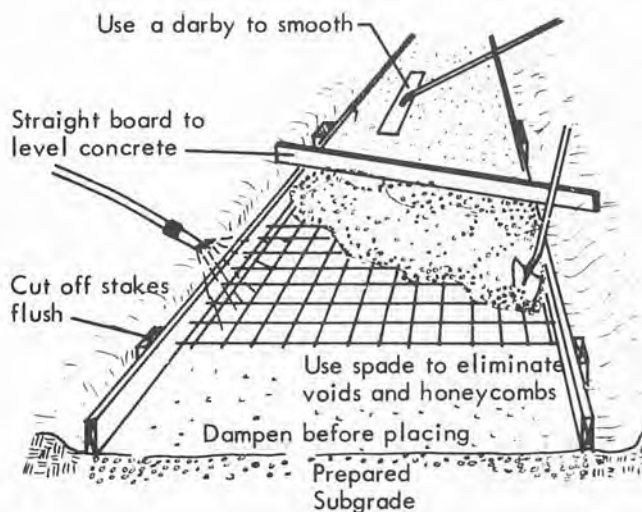


Fig 141-52. Placing concrete.

Remove concrete from wheelbarrows or mixers and spread as soon as possible. After it has been dumped and spread, strike it off to the proper grade, screed the surface, and then darby (using a darby or bull float to smooth and level the surface).

It is very important that the first operations of placing, screeding, and darbying be completed before any bleeding occurs. Bleeding is excess water in the concrete rising to the surface.

When all bleeding water has evaporated and the concrete has started to stiffen, start the other finishing operations, such as edging and jointing.

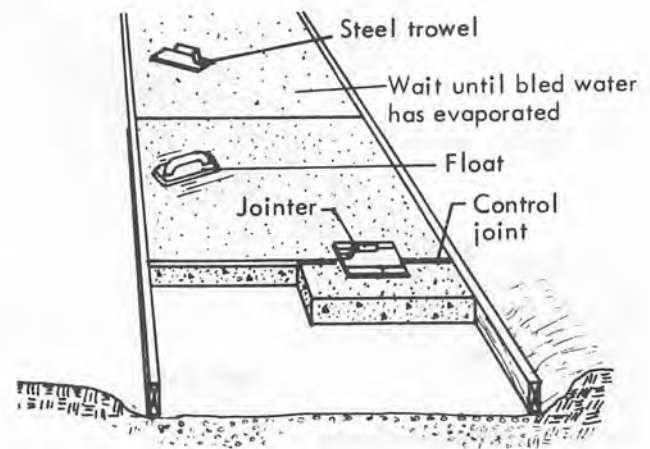


Fig 141-53. Control joints.

Space control joints at intervals equal to width of slab, but not more than 20' apart.

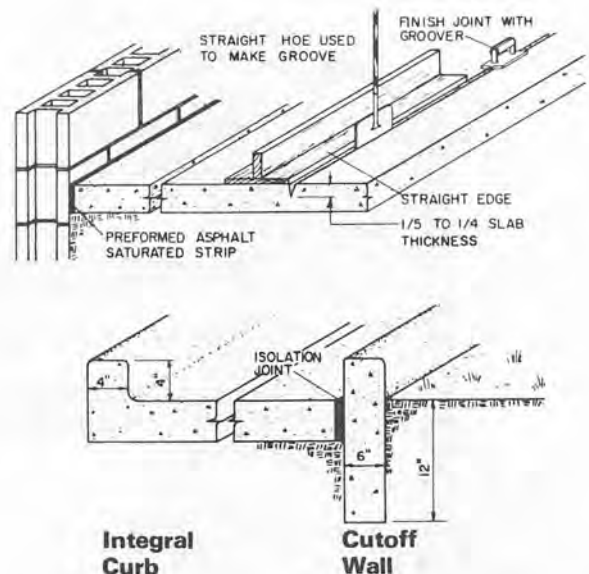


Fig 141-54. Isolation joints.

Place isolation joints along existing improvements such as buildings, water tanks, or paved drives to permit the slab to move with the earth.

Control joints are cut across a slab to control cracking. Cracks, if they occur, will usually be in the joints. Cut control joints soon after the concrete has been placed to work coarse aggregates away from the joints. Space them about as far apart as the concrete is wide.

After edging and hand jointing, float the slab to embed large aggregates beneath the surface, remove slight imperfections and tool marks, and prepare the surface for other finishing.

Final smoothing is done with a steel trowel immediately following floating. If a rough surface is desired, final smoothing is omitted.

Isolation joints permit the slab to move with the earth. Place isolation joints along existing improvements such as buildings, concrete water tanks, or paved drives.

Expansion joints are constructed the same as isolation joints and are installed in new walks and long drives to prevent buckling of the slab during hot weather.

Edges of slabs are thickened to reduce cracking and to allow for some erosion of adjacent soil. Construction joints key adjacent slab pours to each other.

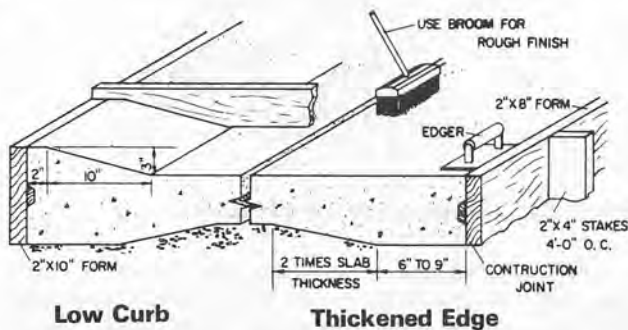


Fig 141-55. Slab edges

Curing

Concrete does not dry—the paste sets by a chemical reaction between cement and water. Keep the surface of the concrete damp at least 5 days. Curing continues for months. Remove forms after about 5 days for slabs, 10 days for walls, 28 days for structural elements.

Outside concrete work in cold weather

Concrete cures very slowly at temperatures below 50°. Water frozen in uncured concrete expands and damages the concrete. Cure concrete at least 48 hrs before it freezes, but preferably 4 to 5 days.

Do not place concrete over frozen ground. Use Type IIIA Portland cement, or Type IA with calcium chloride dissolved in the mixing water at the rate of two pounds per bag of cement.

When air temperatures are below 40°:

- Heat the sand, gravel, and water to just below 150°. Heat the sand and gravel in separate

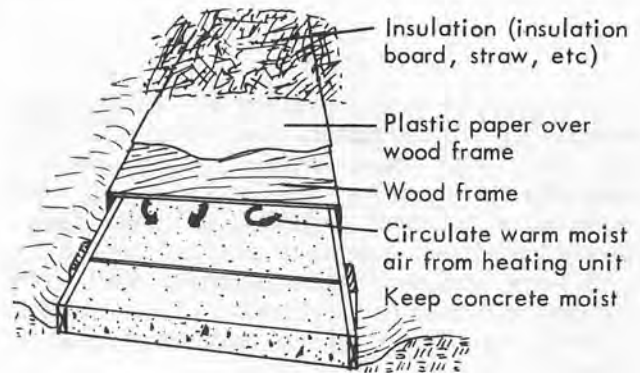


Fig 141-56. Protecting concrete in cold weather.

piles over culvert pipe, smokestack, or other firebox. Place a fire inside. Stir and rake the materials frequently to assure even heating.

- Remove snow and ice from forms before placing concrete.
- Place concrete right after mixing, when the concrete temperature should be 60°-80°.
- Cover the concrete to retain as much heat as possible for 4 to 5 days. Canvas, straw or hay are often used as covers.
- Maintain concrete temperature at 70° for 3 days or 50° for 5 days. Do not allow it to freeze during next 4 days. Use vented heaters indoors.
- Test for sufficient curing: pour hot water on the concrete. If frozen, the concrete will soften, but if properly cured, there will be no effect and forms may be removed.

Outside concrete work in hot weather

As temperatures rise above 70° curing rates increase. Evaporation of water from the concrete also increases. A combination of wind, high temperature, and low humidity dries concrete too rapidly and weakens it.

Keep fresh concrete damp for at least 5 days. Retard evaporation with a sheet of 4 mil plastic over the dampened concrete.

In hot weather it may be necessary to reduce the temperature of the freshly mixed concrete. Stockpile aggregates in the shade, and cool mixing water. Start curing promptly to retard water evaporation.

CHAPTER 142 HOW FARM BUILDINGS FAIL

Although the strengths of various building components (e.g. trussed rafters, pole embedment, bracing, etc.) have been studied, weaknesses or strengths also occur as a result of materials used, construction practices, or misuse of known design recommendations. Building failures caused by large snow and wind loads generally result from inadequate design or carelessness in construction. Failures are limited if an engineered plan is followed.

Truss Spacing

One obvious cause of failure is wide spacing of trusses, where trusses designed for 4' o.c. spacing, for example, are installed 8' o.c., cutting the roof strength in half.

Raised Lower Chords

Raising the lower chord in trusses to gain another 1' or 2' of head room has become common. The strength of this roof frame is limited to the strength of the upper chord from the plate up to the attachment point of the lower chord. Fig 142-1.



Fig 142-1. Raised lower chord roof frame.

If the lower chord is raised only 5" above the plate line of a 40' truss, increase the upper chords from 2x8's to 2x12's. Raising the lower chord 2' increases the tendency to bend in the top chord by almost seven times!

Roof Load Transfer to Poles

In clear-span farm buildings, the sidewall poles are spaced 4'-16' apart. An example illustrates the loading conditions. Assume a 50' wide building with poles spaced 8' apart. Fig 142-2.

Each pole must carry the load from a section of the roof 25' by 8'. This is 200 square feet. A roof load of 25 psf places a 5,000 lb load on each pole. If the trusses are 4' apart, each truss at a pole transfers 2,500 lb to the pole. Each truss between poles transfers 1,250 lb to each pole.

Adequate fasteners transfer the roof load to the pole. If $\frac{1}{2}$ " bolts are used and the lumber is assumed to be Douglas fir, each bolt carries 680 lb (National Design Specification). The total load of 5,000 lb divided by 680 lb is nearly 8. Eight $\frac{1}{2}$ "

bolts, or other fasteners with an equivalent carrying capacity, are needed. If the truss at the pole is secured with two bolts, and each rafter support has two bolts, this provides for three-fourths of the total load. A scab plate below the rafter support is needed to carry a quarter of the load, or 1,250 lb. Pole barn spikes (60d) carry 248 lb each; 5 are needed.

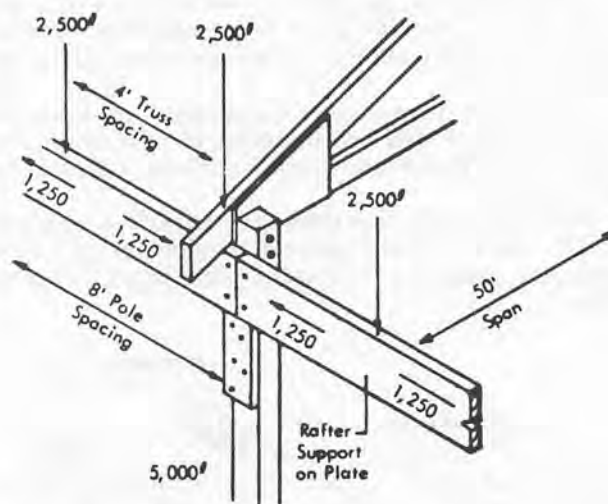


Fig 142-2. Transfer of roof load to pole.

With round poles, fastening the plates or rafter supports to the pole is unquestionably the most critical joint in pole buildings. Even with square poles, it may be impossible to meet all of the edge-distance requirements for bolt locations. The bolts in the rafter supports must be 4 bolt-diameters from the end. With $\frac{1}{2}$ " bolts, this distance is 2"; a 6" wide pole is necessary. With 4" square poles and with round poles, the allowable load per bolt is reduced.

In many pole buildings, the roof load and pole spacing are such that double rafter supports are used—one on each side of the pole. The bolts fastening the ends of the rafter supports to the poles extend through both rafter supports (one on either side of the pole) as well as through the pole. Now in double shear, each bolt carries 1,360 lb in the example building.

Wind Stresses

A wind blowing 100 miles per hour (mph) causes an uplift load on each truss—1800 lb on the example 50' trusses 4' o.c. Trusses not located at poles must be securely anchored to the plates (rafter supports) as shown in Fig 142-3.

Place a vertical bridging anchor on each side of the truss. Secure them to the plates with 8-60d spikes ($8 \times 248 = 1984$ lb). Bolt the truss with $2\text{-}1/2"$ bolts that extend through both vertical bridging members. The bolts are in double shear and each resists 1,010 lb of uplift.

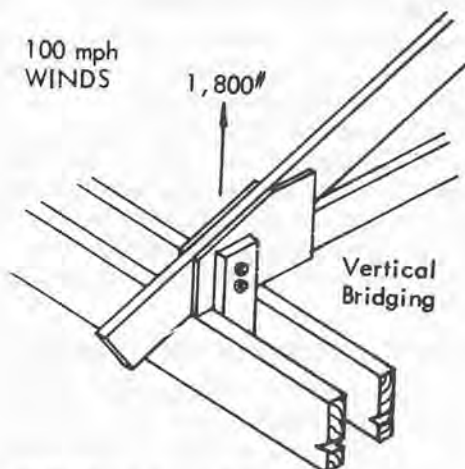


Fig 142-3. Uplift force on each truss.

A study of storm damaged farm buildings in Iowa found that apparently substantial barns were demolished because the builder had not considered fastenings such as adequate roof anchoring. Good fasteners properly applied add little to the cost of a building but can prevent complete building failure or at least reduce the cost of repairs if damage is sustained.

Roof Girt Anchorage

Roof purlins (or girts) are typically 2' apart. Metal roofing is then applied over the roof purlins. The lifting wind forces attempt to pull the roof material off the purlins. Nail metal roofing carefully with screw or ring-shank nails. The purlins transfer the lifting wind forces to the truss upper chords.

Purlin attachments to the trusses can be critically weak. Numerous wind failures of these joints have been observed. If the trusses are 4' apart, and the 2x4 purlins are 2' apart, each joint transfers the wind loads from 8 sq ft of roofing area. For the 100 mph wind, this stress is 144 lb for each joint between purlin and truss. The withdrawal resistance of 10d spikes is 85 lb each; 2 are needed for each joint. In practice, many such joints have only one nail. With trusses designed for wider spacings the 2x4 purlins are on edge to carry the roof load to the trusses. A fastener is needed to secure the $1\text{-}1/2"$ edge of the purlin to the $1\text{-}1/2"$ truss upper chord. If the trusses are 8' apart, rather than 4', the uplift load per joint is doubled to 288 lb. The withdrawal resistance of a 50d spike is 168 lb; 2

are required. This is impossible. Even one driven down through the narrow $1\text{-}1/2"$ dimension is difficult. Many purlins have a couple of 16d toe-nails to secure them to the trusses—Chapter 115 shows toe-nailing reduces withdrawal resistance by $1/3$, so more nails are required.

Wind Bracing of Trusses

The spacing and bracing of trusses is critical, during construction and afterwards. With truss spans of 60' or more proper bracing becomes very important. If one truss buckles or fails, it may well cause all or many of the others to fail. See Chapter 141.

Joint Failures

Building joints are often particularly weak spots. Stud walls, roofing sections, and wall sections often remain intact after a building has failed from wind load. This suggests that "designed" parts of the building (studs, rafters, purlins and girts) are adequate if design recommendations and sound construction practices are followed. Failures occur when rafters give way at the plate, building corners become detached, or purlin and girt fasteners fail from the main frame of the building. In most buildings, and pole frame buildings in particular, splices and trussed rafter connection failures result from inadequate fasteners—the members themselves are never able to be fully loaded.

Excessive snow loads (over 70 psf in some cases) cause roofs to simply collapse. Initial failure in truss rafter designs from snow load appear to be in the lower chord. Excessive tension causes nail or glue-nail joints to fail or the member to fail at a knot or split. Simple rafters fail initially at similar weak points. Rafter supports fail at joint fastenings or weak places in the members.

Most often, trusses fail in the joints. Inadequate glue bonding of the plywood gusset plates to the truss members results from improper glue application and curing. In some collapsed buildings, truss members have separated from the gusset plates, with a clean separation between plywood and dimension members. In a good glue bond wood fibers tear from both members. A good glue-and-nail plywood joint should be at least as strong as the wood itself.

The example 50' span truss, designed for spacing 4' o.c., has stresses in its members of over 6,000 lb, with 25 psf roof load.

The gusset plates on the heel joints, where the upper and lower chords meet, are critical. The plywood plates must be of adequate size, thickness, and grade, and of course glued properly. A 50' truss usually has two splice joints in the lower chord. The tensile stresses in these joints are 5,000 lbs or over; they must be designed accordingly. Avoid putting a splice at a point where the web members

meet the lower chord. Building failures due to this mistake have been observed.

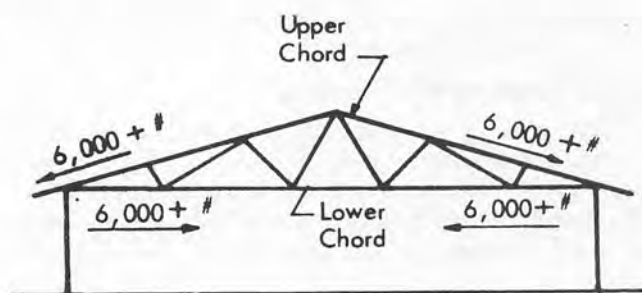


Fig 142-4. Critical stresses in trusses.

Foundation Failures

Any building needs a strong foundation to withstand wind forces. The building must be tied to the foundation with an adequate number and size of fasteners to keep it there.

Pole buildings that are otherwise well constructed may fail if the poles are not properly set. Shallow pole embedments, 2'-3', are often the cause of building failure. Adequate imbedment and concrete backfill help resist both uplift and overturn of a building subjected to high winds.

Other factors contributing to failure include too few (if any) bolts anchoring sill to foundation, poor anchorage of light grain bins, and poor concrete foundations. Inadequate footings, poor drainage, or too shallow foundations can cause destructive settling.

Building Material Failures

Lower grades of lumber than recommended are noted in many failed buildings. Knots and splits may cause main members to fail.

Failure of metal siding and roofing from wind is common. Failures occur where nail heads pull through the metal or with inadequate nailing.

Some failures result from the builder using Interior-type plywood for exterior sheathing, gusset plates on livestock shelter roof trusses, and building braces.

Inadequate Construction Practices

Poor construction practices are found in many buildings. Knee-bracing can be poor or absent, building cross-tie members poorly located, not enough nails used, too small surface area used for joints, or framing members too light for potential loads. Sometimes members are larger than necessary, but splices and joints are poorly made.

With contractors that know how to build a good building, supervision can be poor. The men actually driving the nails must understand the potential problem to get a good job done.

CHAPTER 143 FOUNDATIONS FOR FARM STRUCTURES

A foundation primarily provides a stable base for a building. The foundation distributes the weight of a building and its applied loads over an area of the foundation bed sufficient to prevent unequal or excessive settlement.

Footing Reinforcement

Reinforced footings are used in areas with highly expansive soils, where subject to earthquakes, where a footing "bridges" small areas of poor bearing material in the foundation bed and for unusual structural conditions.

Table 143-1. Load-carrying capacities of soils.

Type of soil	Tons per square foot
Soft clay	1
Firm clay or fine sand	2
Compact fine or loose coarse sand	3
Loose gravel or compact coarse sand	4
Compact sand-gravel mixture	6

Dimensioning Footings Under Walls

Design footings for the type and magnitude of the loads to be carried and the bearing capacity of the soil. Calculate the loads bearing on a 1'-long section of the footing. Determine the required bearing area by dividing the load per linear foot by the bearing capacity per square foot of the soil.

A common rule of thumb is often used to dimension footings for lightly loaded buildings: "the footing is twice as wide, and as thick, as the foundation wall is wide." For example, an 8" x 16" footing is used under an 8" wide foundation wall.

The thickness of larger footings is often arbitrarily made twice the projection of the footing extending from the edge of the wall, Fig 143-1

The bearing area for footings for large buildings, heavily loaded structures, and buildings on poor soils should be calculated. First determine the type of soil and its bearing capacity; then calculate the dead and live loads. Then determine the amount of bearing area required:

$$A = \frac{P}{W}$$

where

A = minimum bearing area of footing in square feet

P = live + dead loads in lb/ft of foundation

W = allowable soil bearing pressure in pounds per square foot (psf)

Since, the footing calculations are for a section of the footing 1' long, "A" in the formula is the required width of the footing at that point.

Reinforce footings up to about 10" x 20" with two No. 4 longitudinal bars.

For larger footings, determine the amount of longitudinal steel with the formula:

$$A_s = 0.0025 \text{ bd}$$

where

A_s = area of steel, sq. in.

b = footing width, in.

d = effective depth of footing, from top of footing to center of steel, in.

For heavy wall loads, use column footing designs given earlier in this chapter. For example, the allowable load on a 20" square footing is multiplied by 12"/20" for the allowable load per foot of foundation wall.

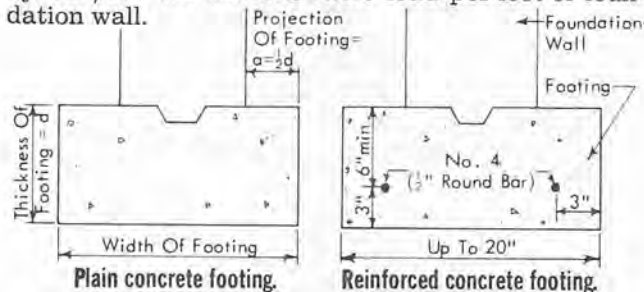


Fig 143-1. Concrete wall footings.

Foundation Wall Design

Foundation wall width depends on the vertical loads, lateral pressure of the earth, and the unsupported height and length of the wall. Foundation walls for most small buildings are 8" - 12" cast-in-place concrete or concrete masonry.

Use 8" foundation walls no more than 4' into the earth, or 7' in stable, well-drained soils. The total height of a foundation wall and masonry superstructure should not exceed 35' for a 8"-10" thick foundation wall. For buildings in poor or very wet soils, the foundation wall should be at least 12" thick.

Foundation Construction

Level foundation beds and the bottom of excavations, so footings bear evenly on the soil. Place the bottom of footings of major buildings below frost to protect them against frost heave.

Place footings on undisturbed earth. When fill is necessary, place it in 6" layers and compact it thoroughly. Remove the material in soft spots, add well consolidated fill.

Cast-in-place foundation walls may be cast with the footing or separately. When the footing is cast first, form a tapered groove in the top of the footing for a construction joint. Use an oiled beveled piece of wood, and remove it when the concrete is sufficiently hard.

Foundation Drainage

Excessive water lowers the bearing capacity of almost all soils. In wet areas, drain the foundation with a drain tile beside the footing. The drain outlet should be always open.

Place drain tile 1/4" apart to permit entry of the water into the drain. Place coarse granular fill around tile lines. Gravel prevents erosion of the water-bearing soil, speeds water movement and aids in preventing silt build-up in the tile.

The mortar joints on the inside and outside of concrete masonry basement walls should be carefully tooled to compress the mortar and make the joints more watertight.

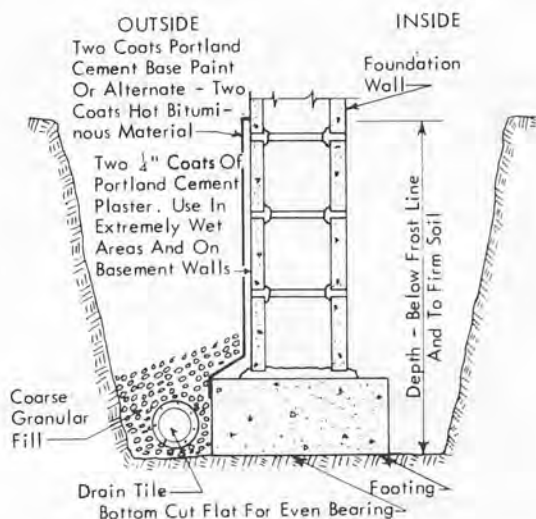


Fig 143-2. Proper foundation drainage and wall treatment help ensure dry buildings.

Protection and Backfilling of Foundation Walls

Do not permit water to accumulate next to foundation walls. Water exerts pressure and when several feet deep can push in newly constructed walls. Grade the area so no surface drainage enters the excavation. Install roof gutters and downspouts.

Backfill carefully. It is usually best to delay backfilling until the floor is constructed (preferably after the building has been constructed), when the foundation walls have greater stability.

A grade beam foundation is a series of concrete piers that support a reinforced beam around the building. The grade beam supports the building and its superimposed loads.

Piers

Piers carry loads by direct bearing on the soil.

Extend below the frost line to firm bearing. Piers should have a diameter of at least 10". The bottom of the pier hole is often enlarged to increase the bearing area and increase uplift resistance.

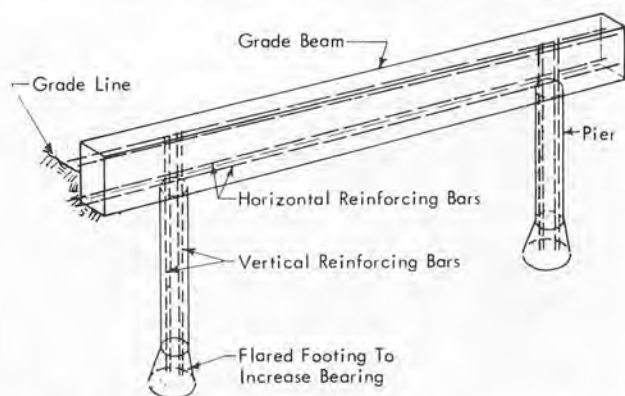


Fig 143-3. Grade beam foundation consists of series of piers supporting continuous reinforced beam around perimeter of building.

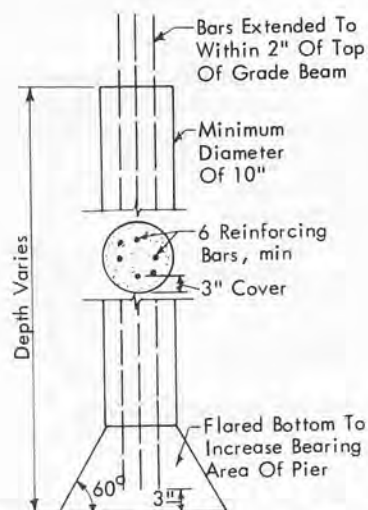


Fig 143-4. Piers support grade beam. Reinforcing steel extends to within 2 in. of top of grade beam.

Column footings are used where the loads are heavy, requiring more bearing area than a flared round footing.

Reinforce piers to resist lateral forces, to tie the pier and beam together, and to resist tensile stresses from foundation uplift by expanding soil or frost heave. The diameter of the flared bottom or bell is sized for the allowable bearing pressure of the foundation bed. The diameter of the shaft is sized for the allowable bearing pressure of concrete. Determine the area of reinforcement by assuming the shaft acts as a column with vertical loads and moments.

Minimum reinforcing steel area is 0.01 times the cross-sectional area of the pier, or 6 - #4 bars. The vertical steel should have a cover of 3" and should extend from 3" from the bottom of the pier to 2" from the top of the grade beam.

Grade Beams

The sizes of live and dead loads of the building and the distance between the piers determine the size and reinforcement of grade beams.

Determine the load per foot of wall on the grade beam. Select a beam from the tables given earlier in this chapter.

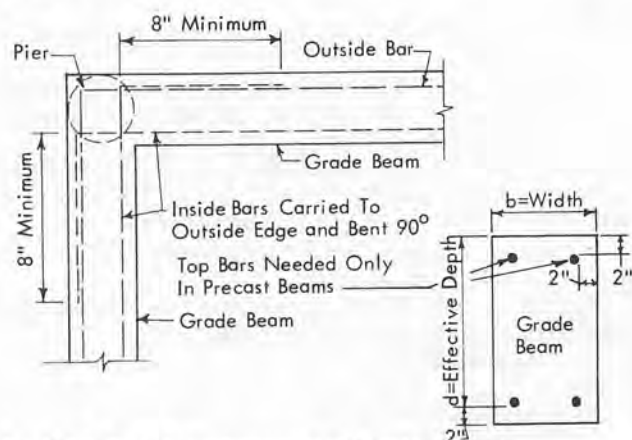


Fig 143-5. Grade beam dimensions and steel placement.

CHAPTER 144 SELECTING AND SETTING POLES*

Pole-type construction utilizes preservative-treated poles set in the ground as main structural members. Usually, the poles furnish both vertical support for the building, and also fixity at the bottom against rotation, to provide lateral bracing. Selecting and setting the poles is very important in pole building construction.

Wood Species

Strength properties of poles depend largely on the species of the wood. Table 144-1 lists the ultimate fiber stress in the outer fiber of the pole at failure in flexure as a cantilever beam. The values are less than average test results to provide a safety factor for variability and for the effect of preservative treatment on strength. Note that weaker species are listed first. Other strength properties are also important, but the stress in bending is usually the limiting factor for poles used in pole buildings.

Wood Quality

The average growth rate measured at the butt in the outer 2" of poles should not be less than 6 rings/in., except that 4 rings are acceptable if 50% or more summerwood is present.

Prohibited defects are:

- Cross breaks, decay, dead streaks.
- Holes, open or plugged, except plugged test holes up to 1/2" diameter.
- Hollow butts, tops, and pith centers.
- Sap stain with softening or other wood disintegration.

Limited defects are:

- Firm red heart, with no softening or disintegration.
- Compression wood, if not visible in the outer 1" of the pole.
- Insect damage, if no holes are over 1/16" diameter or channeling is over 1/16" deep.
- A knot, if not over 2". The sum of knot diameters in 1' should not exceed 4" in poles to 16' long, or 5" in longer poles.
- Dead knots, if any decay is not associated with heart rot.
- Scars, if smoothly trimmed and not over 1" deep.
- Shakes, if 2" or more from the surface of the pole.
- Spiral grain, if not over one complete twist/30'.
- A split (or 2 checks terminating at the pith and separated at least 1/6 of the circumference), if not more than 6" along the upper section of the pole.
- Shape defects are limited to sweep in only one plane and no "excessive" kinks or crooks. See Fig 144-1.

Preservative Treatment

Use poles preservative-treated to prevent decay and insect damage. The process used for pressure-injecting preservatives must assure adequate penetration and uniform diffusion throughout the treated area. Wood preservatives fall into two broad groups, oil-borne chemicals and water-borne salts. The most common oils are creosote and pentachlorophenol.

Table 144-1. Wood species for construction poles.

Species		Code Letters*	Fiber Stress, psi†	Modulus of Elasticity, psi
Common Name	Botanical Name			
Cedar, northern white	Thuja occidentalis	EC	4,000	880,000
Cedar, western red	Thuja plicata	WC	6,000	1,100,000
Pine, ponderosa	Pinus ponderosa	WP	6,000	1,100,000
Pine, jack	Pinus banksiana	JP	6,600	1,100,000
Pine, lodgepole	Pinus contorta	LP	6,600	1,320,000
Pine, red (Norway)	Pinus resinosa	NP	6,600	1,320,000
Douglas-fir, interior north	Pseudotsuga menziesii	DF	8,000	1,760,000
Douglas-fir, coast type	Pseudotsuga menziesii	DF	8,000	1,760,000
Larch, western	Larix occidentalis	WL	8,400	1,760,000
Pine, southern				
Loblolly	Pinus taeda	SP	8,000	1,760,000
Longleaf	Pinus palustris	SP	8,000	1,760,000
Shortleaf	Pinus echinata	SP	8,000	1,760,000
Slash	Pinus elliotii	SP	8,000	1,760,000

ASAE-R-299

*Code letters denoting pole species.

†Ultimate fiber stress, psi, in the outer fiber of the pole at failure in flexure as a cantilever beam. The values are slightly reduced from average test values to provide for variability and for the effect of preservative treatment on strength. It is customary to reduce the stresses further for use in design to provide a factor of safety in accordance with the type of construction in which the poles are used.

*From a paper prepared for Farm Structures Day, University of Illinois, Urbana, 11/21/68, by Dr. D.L. Day, Department of Agricultural Engineering, U. of Illinois, and ASAE-R299,

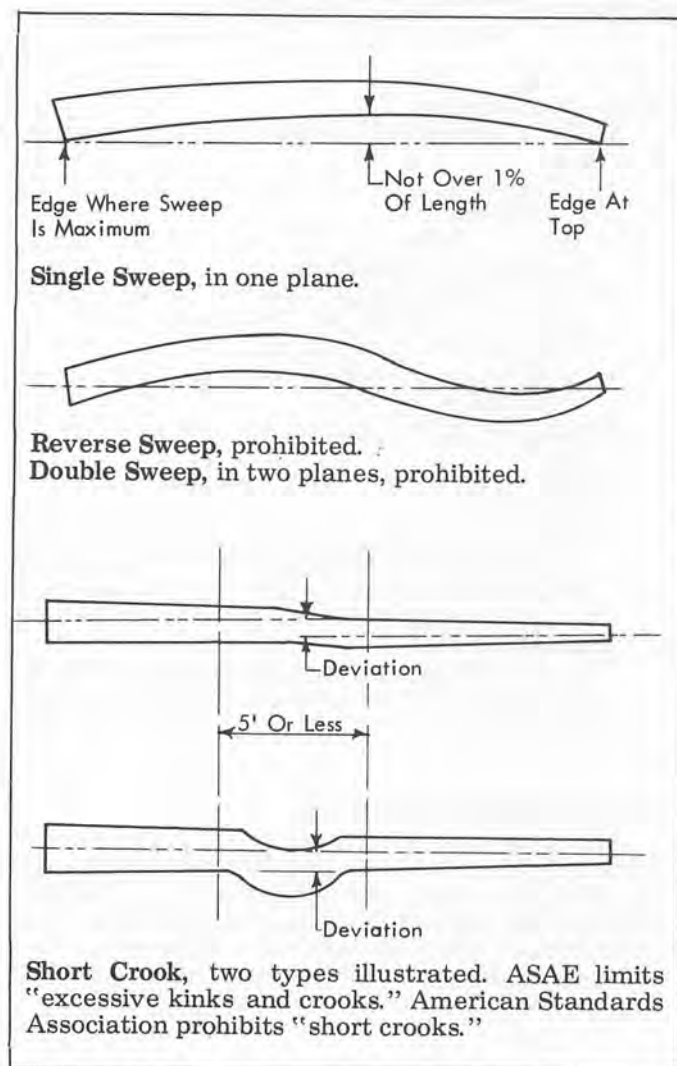


Fig 144-1. Pole shape limitations.

Wood preservatives should conform to the latest edition of the American Wood Preservers Association standards listed in Table 144-2. Wood preservatives where paintability, cleanliness, or freedom from odor are required should be applied only to air-seasoned or kiln-dried poles with moisture content below 30% in the sapwood.

Identification Markings

For identification of graded poles, certain information should be branded on the pole or included on a tag affixed to the pole. Obviously, it is better to brand poles on the side, for better identification after construction. Brands or tags on pole ends are lost, since one end of the pole is put into the ground and the other may be cut off during construction.

Table 144-2. Wood preservatives.

American Wood Preservers Assoc. Standards	Min Retention, lb per cu ft of gross volume*	
Creosote—AWPA P1, Standard for Coal Tar Creosote for Land and Fresh Water Use	8,	10
Pentachlorophenol—AWPA P8, Standards for Oil-Borne Preservatives; and AWPA P9, Standard for Hydrocarbon Solvents for Oil-Borne Preservatives	0.4,	0.5

*Higher retention is for severe service conditions such as occur in the area south of the 40th parallel of latitude and east of the 100th meridian of west longitude. Min retention for pressure-treated Western Red Cedar is 4.5 lb per cu ft and for thermal treatment is 20 lb of creosote or pentachlorophenol solution in the outer 1/2-in. zone of the pole. These retentions are based upon gage measure. Where American Wood Preservers Association Standard, AWPA C4, Poles-Preservative Treatment by Pressure Processes, provides for assay measure, the required retentions shall be those corresponding to assay measure in the stipulated sampling zone for the species.

Preservative, per AWPA P5*	Min Retention, lb per cu ft of Gross Volume
Ammoniacal copper arsenite	0.5
Chromated copper arsenate (type A)	0.75
Chromated copper arsenate (type B)	0.42 (anhydrous)

*American Wood Preservatives Assoc. AWPA P5, Standards for Water-Borne Preservatives.

Dimensions

Length is measured between the ends and may be +6" or -3".

For species of fiber stress other than in Table 144-1, the circumference at the groundline is:

$$C = \sqrt[3]{\frac{wl}{0.000264f}}$$

where

C = groundline circumference, in.

w = breaking load 2' from top of pole, lb.

l = length between groundline and load, ft.

f = ultimate fiber stress in bending, psi.

The groundline circumferences thus obtained can be converted to circumferences at 6' from the butt by means of an average diameter taper of 0.1 in./ft of length. When the poles are not perfectly round, the size is determined with a circumferential tape.

Classification. The true circumference class is determined as follows: Measure the circumference at 6' from the butt. This dimension determines the true class of pole, provided that its top, measured at the minimum length point, is large enough. Otherwise the circumference at the top determines the class.

Fig 144-2 is a graphical presentation of wood pole dimensions based on a uniform taper from minimum top circumference to minimum groundline circumference. It is convenient for determining approximate pole dimensions at any point, and for converting from one property to another (e.g. section modulus to circumference).

Round Vs. Sawn or Slabbed Poles

For convenience in handling and attaching other structural members, sawn timbers are often used as columns instead of natural, round poles. However, round poles have two strength advantages. A round pole is 18% stronger in bending than a similar column with a rectangular cross-section of the same area, and, strength of a round pole is reduced very little by knots if limbs are not trimmed close enough to expose excessive cross-grain.

Longer life is expected from round, pressure-treated poles because the sapwood is easier to treat than the exposed heartwood of sawn columns.

Poles are slabbed above the groundline on one or more sides before treating as a compromise between round and sawn. The butt section retains its thick envelope of thoroughly impregnated sapwood in the soil, where wood-destroying organisms are usually most active. Slabbing is a minimum cut to provide a single continuous flat face from groundline to top of intermediate wall poles, or two continuous flat faces at right angles from groundline to top of corner poles.

Depth of Set (see Chapter 133)

Provide fixity at the base of the pole for structural stability against wind, snow, and ice loads. Both lateral and vertical design pressures vary considerably with soil conditions, reducing the practical value of equations for depth of set. Past experience is helpful in deciding on the depth of set and the material to be used around the pole. Usually, concrete provides necessary footing beneath the pole.

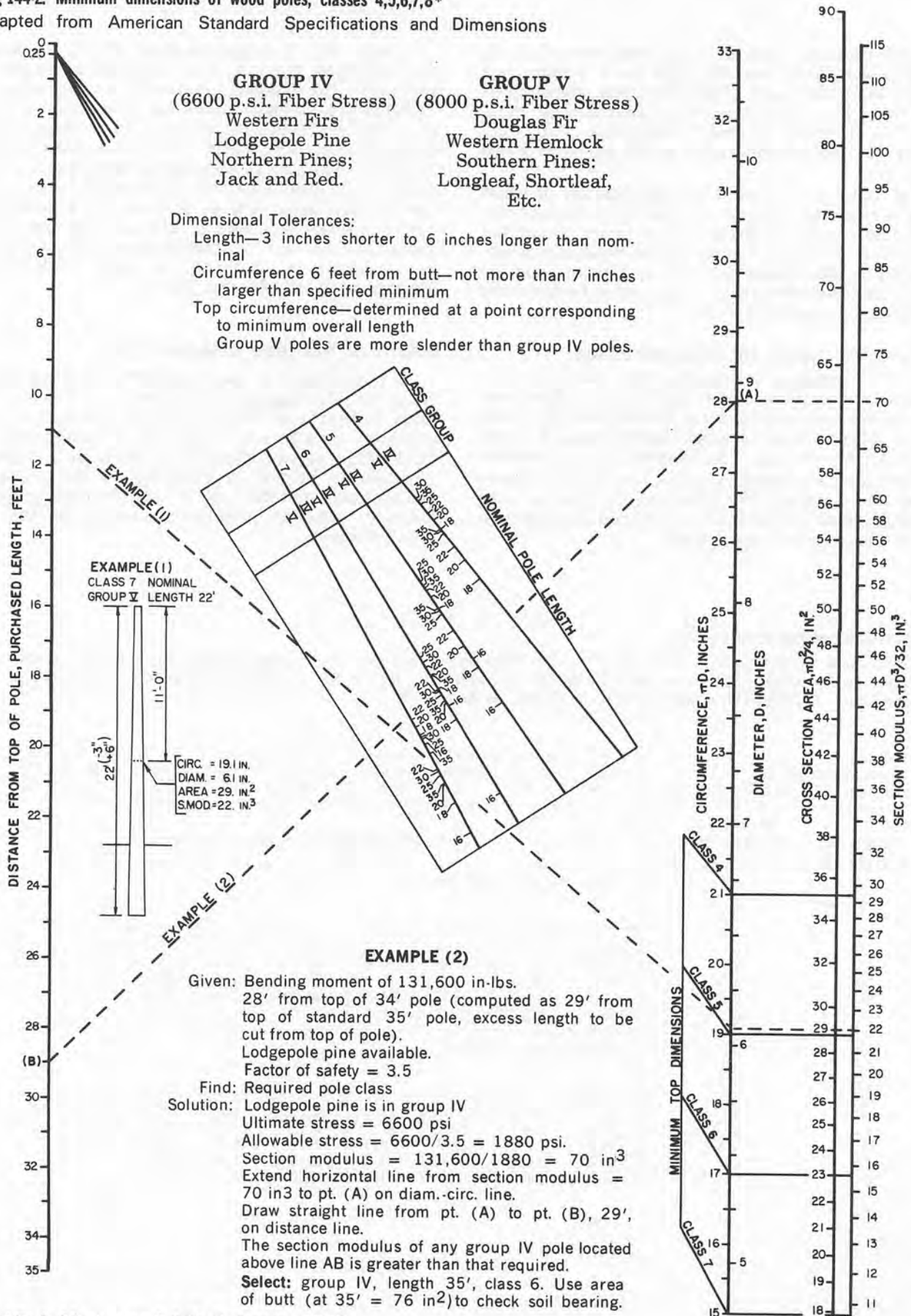
Table 144-3. Dimensions of wood poles.

Breaking load is horizontal, 2' down from the pole top. Groundline is for requirements on slabbing, scars, straightness, or other. For poles to 16', 6000 psi, and 18', 8000 psi: minimum circumference = top circumference + 0.075 in./ft taper; for 18', 6000 psi, = 0.1 in./ft.

Class	A = 1	B = 2	C = 3	D = 4	E = 5	F = 6	G = 7	H = 8	J = 9
Breaking Load, lb	4,500	3,700	3,000	2,400	1,900	1,500	1,200	740	370
Min Circumference at Top, in.	27	25	23	21	19	17	15	15	12
Length of Pole, ft	Groundline Distance from Butt		Min Circumference at 6 Feet from Butt, in.						
12	3		Fiber Stress = 6000 psi						
14	3								
16	3.5								
18	3.5								
20	4		33.5	31.5	29.5	27.0	25.0	23.0	21.5
25	5		37.0	34.5	32.5	30.0	28.0	25.5	24.0
30	5.5		40.0	37.5	35.0	32.5	30.0	28.0	26.0
35	6		42.5	40.0	37.5	34.5	32.0	30.0	27.5
40	6		45.0	42.5	39.5	36.5	34.0	31.5	29.5
12	3		Fiber Stress = 8000 psi						
14	3								
16	3.5								
18	3.5								
20	4		31.0	29.0	27.0	25.0	23.0	21.0	19.5
25	5		33.5	31.5	29.5	27.5	25.5	23.0	21.5
30	5.5		36.5	34.0	32.0	29.5	27.5	25.0	23.5
35	6		39.0	36.5	34.0	31.5	29.0	27.0	25.0
40	6		41.0	38.5	36.0	33.5	31.0	28.5	26.5

Fig 144-2. Minimum dimensions of wood poles, classes 4,5,6,7,8*

Adapted from American Standard Specifications and Dimensions



Stabilizing the Pole

Agricultural Engineers at Oklahoma State tested the withdrawal and settling of poles under load for the 3 anchorages of Fig 144-3.

Each pole was loaded in increments of 800 lb, with a week between increments until 3,200 lb was supported. The amount of settlement was recorded for 15 months. After the settlement trials, the poles were withdrawn and the required uplifting forces measured.

Bearing pads can be precast or cast in the holes before the poles are erected. After the poles are placed and positioned, concrete can be cast around the butt. Spikes or lag screws in the butt assure bond with the concrete.

The study results are valid only for their soil type, but are approximate for predominantly clay soils.

Poles without concrete encasements settled excessively.

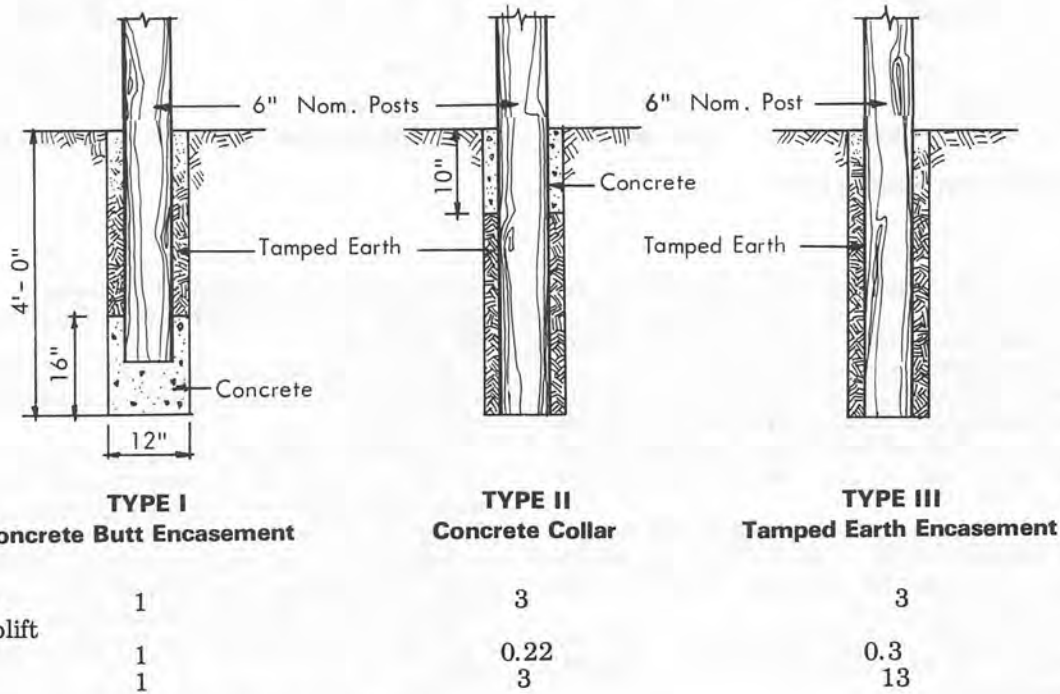


Fig 144-3. Pole anchorages in settlement and withdrawal tests.

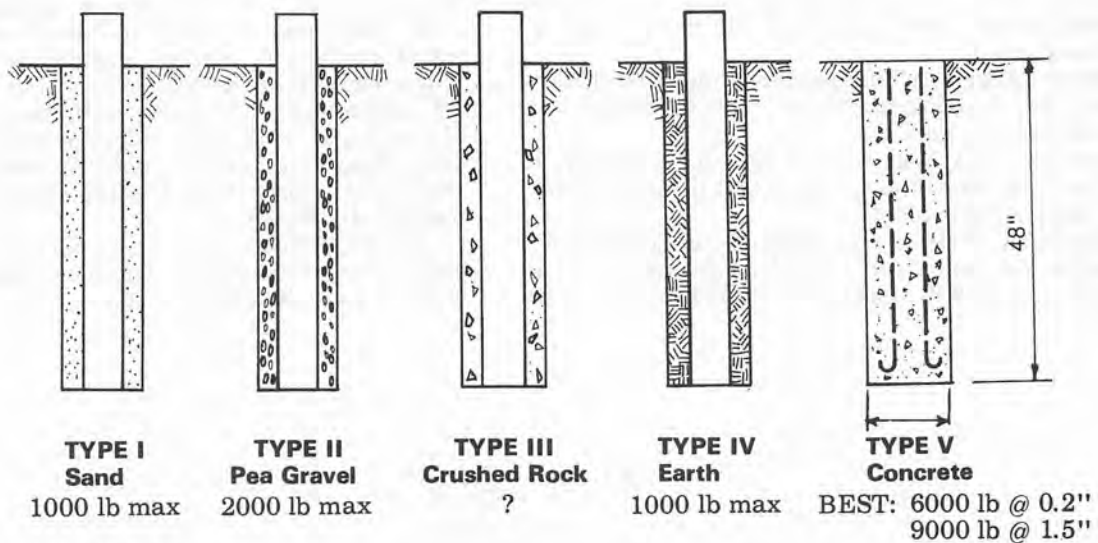


Fig 144-4. Anchorage backfill materials.

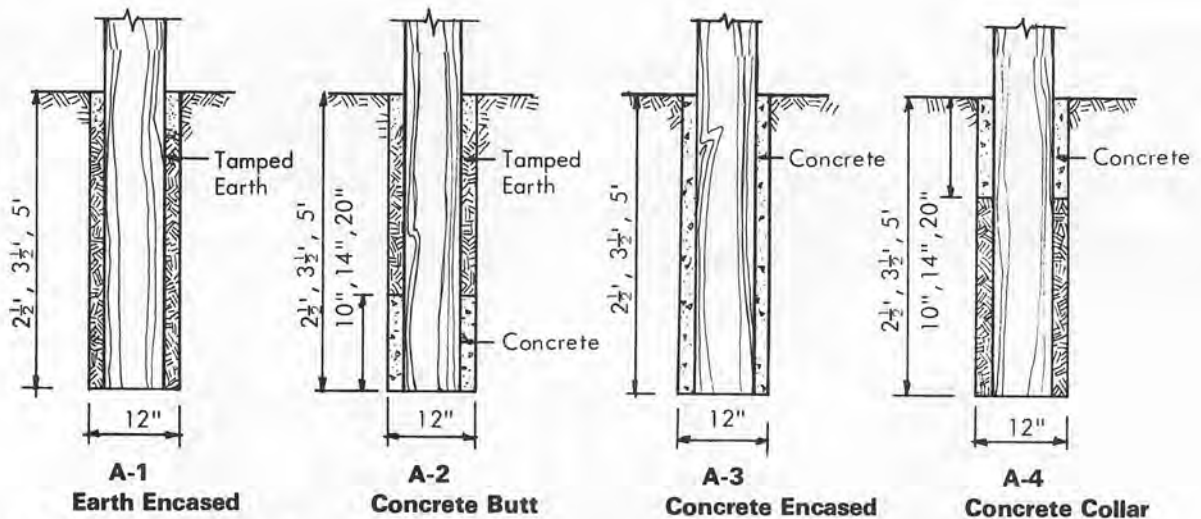


Fig 144-5. Pole anchorages in stability tests.

The poles with concrete butt encasement developed 4.5 times as much uplift resistance as poles with concrete collars, and 3.5 times as much as those with tamped-earth encasement.

The poles with concrete butt encasement developed maximum withdrawal resistance at 1/3 the vertical travel of poles with the concrete collar, and about 1/13 that of poles with tamped-earth encasement.

Vertical withdrawal tests were made of five types of backfill shown in Fig 144-4. The results are valid for only one soil, but indicate relative values in predominantly clay soils.

Earth- or crushed rock-packed anchorages developed about 900 lb resistance before noticeable vertical movement.

Tamped earth and sand yielded at a relatively constant withdrawal load once they started to yield, while the resistance of gravel-packed anchorages increased to a maximum at about 2" of vertical movement, and then decreased as vertical movement continued.

Gravel-packed anchorages developed about twice (2,000 lbs) as much resistance to withdrawal than tamped earth or sand.

Concrete was best with 6,000 lb resistance at 0.2" vertical movement, and 9,000 lb at less than 1.5" vertical movement.

Overturn tests were made with nominal 5"-minimum-top poles 18' long for 2.5' and 3.5' embedment, and 20' long for 5' embedment. A hori-

zontal pull was applied 14' above the ground, at the rate of 100 lb/min up to 800 lb for 3 cycles for each pole.

Increasing depth of set from 2.5' and 3.5' to 5' reduced movement to 38% and 30% respectively, of that at 2.5'.

Concrete instead of earth reduced deflections to 2/3 or less of the well-tamped earth backfill, with little difference between partial and complete filling with concrete.

Depth affected deflection rates most during the first load application. Subsequent loads tended to produce more uniform deflection rates, but permanent deflection was greater for the shallower anchorages.

Differences in deflection between the first and subsequent loading cycles were greater than differences from either anchorage or depth.

Some concrete encasements broke; reinforcing the casement with wire mesh appears desirable.

In clay soils, a relatively small increase in soil water content causes a considerable loss in stability. Deflection rates increased over seven times for anchorages 2.5' deep, with the water content of the upper 3' at 17% or higher, than when below 15%. Therefore, divert roof and surface drainage and avoid poorly drained sites when planning pole-framed structures.

The best anchorage is a concrete encasement, with a concrete-butt encasement around the lower third of the pole a close second.

CHAPTER 145 REMODELING CORN CRIBS FOR SMALL GRAIN STORAGE*

Introduction

An ear-corn crib can be economically remodeled for shelled corn storage if it is sturdily built and in good condition. With a few alterations, the crib can be converted into a bin that provides adequate storage and protection.

Reasons for Remodeling

- Ear-corn cribs usually cannot contain shelled corn. The corn will pass through the openings needed for air movement through ear corn.
- The structural parts of the crib will not support the added weight and pressure of shelled corn. Shelled corn weighs two thirds more and exerts three and one-half times the pressure of ear corn.
- Remodeling will usually cost less than the construction of a new storage.

What Must Be Remodeled?

The parts of an ear-corn crib that will usually need altering include:

1. The walls and floors need strengthening.
2. The walls and floors need to be covered with screening or siding that will contain and in some cases protect the shelled corn.

Should You Remodel?

- YES**, if 1. The needed additional strength can be obtained by making reasonably simple, low-cost alterations.
2. The cost of remodeling is less than one-half the cost of a new structure. A higher cost is sometimes justified where there are already facilities such as an inside elevator, overhead bins, etc.
3. The crib is conveniently located for:
- Expansion of it and/or related facilities.
 - Integration into a feed processing and handling center.
 - Provision for large electrical loads.
 - Installation of below-grade equipment without flooding (example—elevator pit).
- NO**, if 1. The crib must be moved to another location on the farm in addition to being remodeled.
2. Major structural changes are required. These include new foundations, a new floor, or extensive replacement or addition of studs, poles, or other framing members.

3. The cost of the remodeling will be more than one-half the cost of a new structure.
4. The remodeled crib cannot maintain the desired grain quality or cannot be easily maintained.

Remodeling Procedure

There are three basic steps in remodeling almost any type of ear-corn crib:

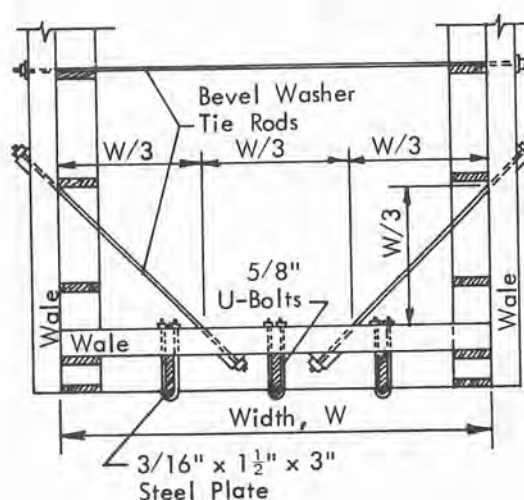
1. Strengthen the structure.
2. Make the walls grain-tight (also weather-tight if long storage periods are desired).
3. Provide for moving the shelled corn into and out of storage.

Strengthening Stud—Frame Cribs

Walls

One practical way to strengthen stud walls is to install wales (horizontal stay timbers) and tie rods. The number and size of wales and tie rods needed depends on the stud height, size, and spacing. See Table 145-1.

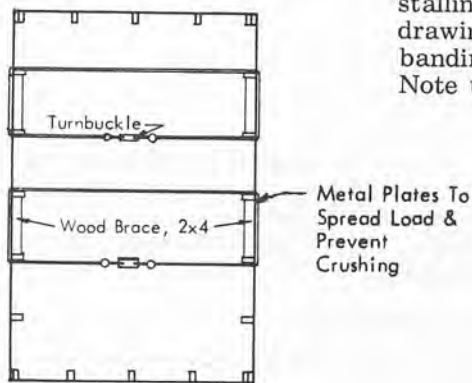
On an End Wall, the wale is run on the inside of the cribbing so that it will not interfere when there are sliding doors on the driveway. Diagonal tie rods are used at the corners to connect the wale with those on the adjacent side walls. Wales and tie rods should be the same size as those on the side walls.



*This publication is a revision of University Illinois Circular 775 based on work by Dr. J.O. Curtis, Agr. Engr. Dept., University of Illinois.

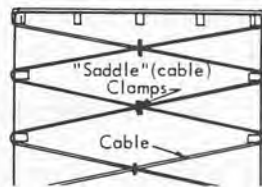
Sidewall Reinforcement

Another practical way to strengthen stud walls is to install steel bands or cables across the crib. Several recommended ways of installing these ties are shown in the following drawings. The number and size of cable or banding to install is listed in Table 145-1. Note that no wales are used.

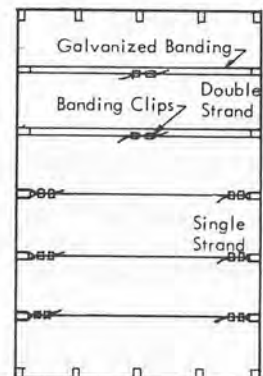


Cable - Turnbuckle Method

Tighten the cables with turnbuckles or some other method such as a fence tightener.



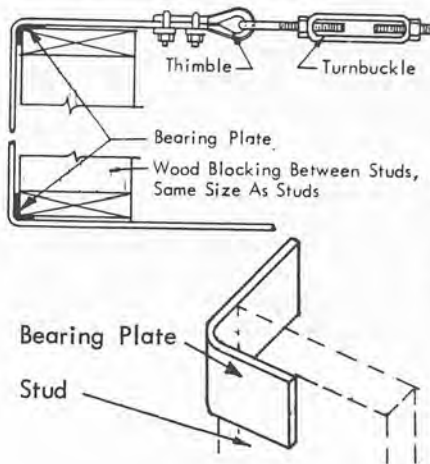
Cable "Shoelace" Method



Steel Banding Method

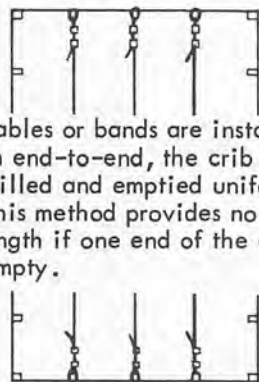
Install double clips on all bands. Avoid damaging the galvanizing.

Bearing Plate Details

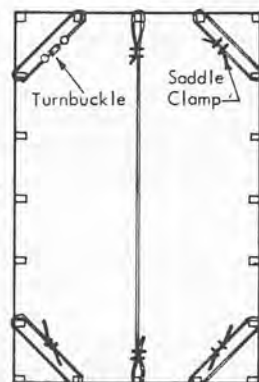


End Wall Reinforcement

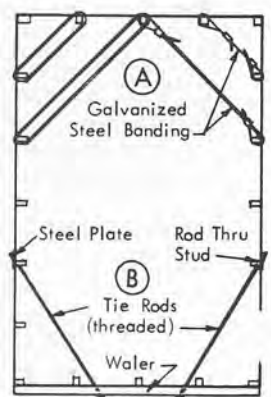
If cables or bands are installed from end-to-end, the crib must be filled and emptied uniformly as this method provides no strength if one end of the crib is empty.



Steel Banding Method



Turnbuckle or Clamp & Cable Method

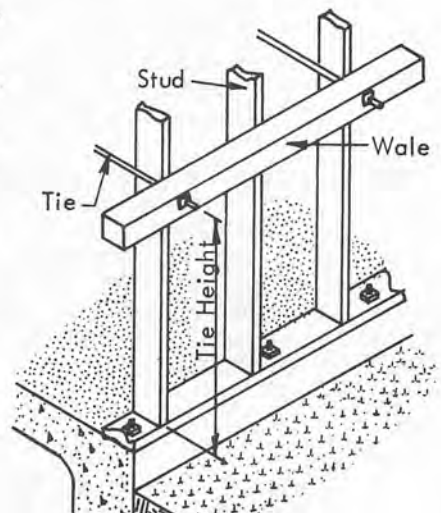


(A) Steel Banding (B) Tie Rod - Waler

Table 145-1. Recommended size, spacing, and location of structural members—stud frame cribs.

Stud Height	12'	14'	16'	18'	20'
Stud Size	2x6 24" o.c.	2x6 18" o.c. or 2x8 24" o.c.	2x6 12" o.c. or 2x8 24" o.c.	2x8 18" o.c. or 2x10 24" o.c.	2x8 12" o.c. or 2x10 18" o.c.
Tie Heights	6 1/2'	6 1/2'	6 1/2'	7'	7'
Tie Spacing	4'	4'	4'	4'	3 1/2'
Threaded Rod Size	5/8"	3/4"	7/8"	7/8"	1"
Unthreaded Rod Size	5/8"	5/8"	3/4"	7/8"	7/8"
Wale Size	4x6	4x6	4x6	6x6	6x6
Install bands or cables 24" o.c.					
No. of Bands	1	1	2	2	2
Cable Size#	3/8"	7/16"	1/2"	1/2"	9/16"

*1 1/4" x 0.044" high tensile steel strapping, galvanized.
#6 x 7 regular lay mild plow steel cable.

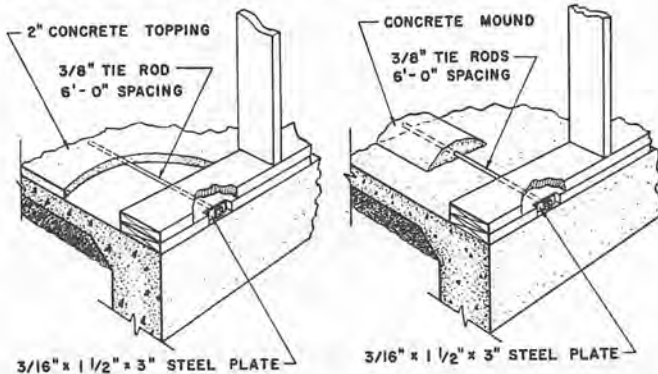


The connections at the top and bottom of studs usually need strengthening also. The sills must be firmly anchored to the foundation wall, with the anchor bolts spaced as follows:

Anchor Size	Concrete Floor With Single Sill	Concrete Floor With Double Sill	Wooden Floor
1/2 in bolt	2 feet o.c.	2½ feet o.c.	6 feet o.c.
5/8 in bolt	2½ feet o.c.	3½ feet o.c.	6 feet o.c.

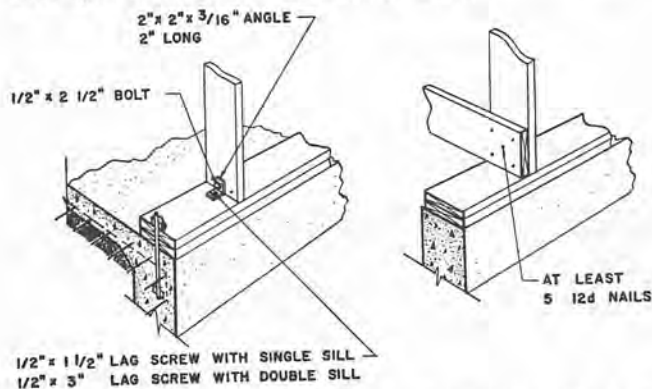
If the present anchor bolts are inadequate, tie rods may be installed as shown below.

If metal stud sockets were used in constructing the crib, the connection at the base of the studs is probably adequate without change.



For easier emptying, cover the rod with a new layer of concrete (left) or a small mound of concrete (right). To secure a board between the old floor and the new concrete, wash the floor thoroughly and leave it damp.

The bottom ends of studs must be securely fastened to the sill. Use four tenpenny nails for 2x6 studs, six for 2x8 studs, and eight for 2x10 studs, or use anchors as shown below.



Tie top ends of the studs with ties as outlined below:
Table 145-2. Tying studs at the top.

Stud height (feet)	Stud size	Stud spacing (inches)	Tie size	Tie spacing (feet)	Nails at each end of tie
12	2x6	24	2x4	4	4 12d
14	2x6	18	2x4	4½	5 12d
14	2x8	24	2x4	4	5 12d
16	2x6	12	2x4	4	6 12d
16	2x8	24	2x4	4	6 12d
18	2x8	18	2x6	4½	8 12d
18	2x10	24	2x6	4	8 12d
20	2x8	12	2x6	3	8 12d
20	2x10	18	2x6	3	8 12d

Foundations and Floors

If the crib has concrete foundation walls at least eight inches thick and a concrete floor in good condition resting on firm subgrades, it will be able to resist the additional load of shelled corn.

The floor for cribs with wooden joists resting on concrete foundation walls will need strengthening. The size of joists needed are listed in Table 145-3.

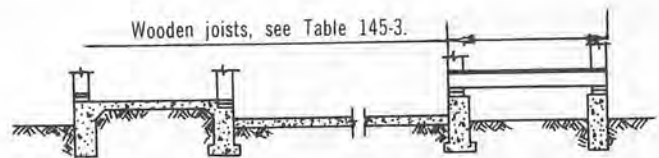
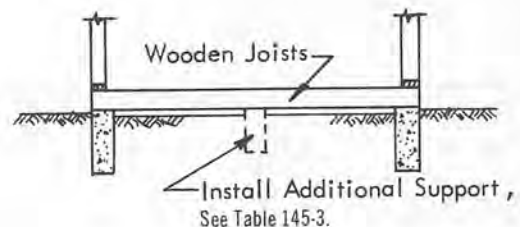


Table 145-3. Size of joists spaced 12 inches on center.

Height of Crib	Span			
	4	6	8	10
8	2x6	2x8	2x10	2x12
10	2x6	2x10	2x12	*
12	2x6	2x10	2x12	*
14	2x8	2x10	*	*
16	2x8	2x12	*	*
18	2x10	2x12	*	*

*Install a center support to reduce the span, thereby reducing the size of joist needed. This will normally require removing some of the floor.

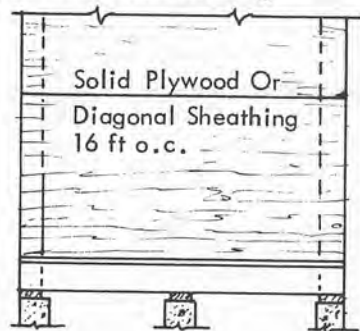
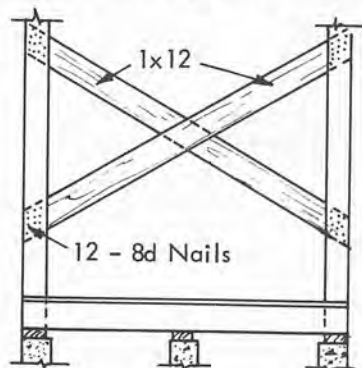


The size of foundation needed depends on the quantity of corn to be stored and the type of soil under the foundation. Foundations should extend 30 inches into the ground. If the foundation supports all of the weight of the corn, as with a wooden floor, the foundation should have one square foot of bearing surface for each 70 bushels of stored corn. A greater load would bear too heavily on the soil. If the size of footing cannot be estimated, the area of the foundation wall surface can be considered approximately equal to the area bearing on the soil.

Wind Bracing

Braces for resistance to wind should be installed each four feet in cribs with overhead bins and each eight feet in cribs without overhead bins.

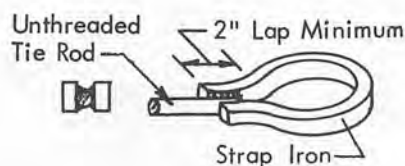
If cross bracing is not already in place, install solid partitions in the crib about 16 feet apart. Use plywood or diagonal sheathing.

Recommended Bracing**Optional Bracing, 4 to 8 feet o.c.****Strengthening Pole Cribs**

Most pole cribs will need sidewall strengthening. Install either threaded or unthreaded tie rods as listed in Table 145-5. Connect unthreaded tie rods using strap iron as specified in Table 145-4. Connect threaded tie rods with turnbuckles or other methods of tightening.

Table 145-4. Size of strap iron needed for unthreaded tie rods.

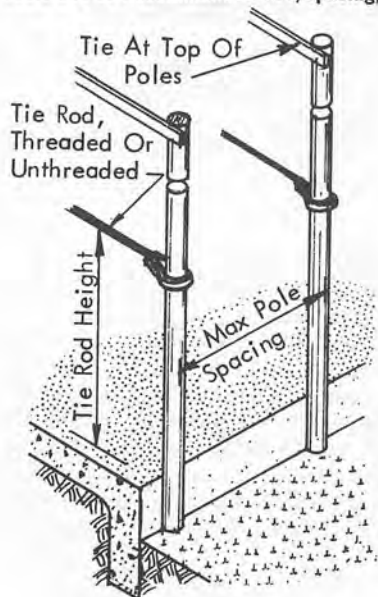
Tie Rod	Size at Strap Iron
1/2"	1/8" x 1"
5/8"	3/16" x 1"
3/4"	3/16" x 1 1/4"
7/8"	1/4" x 1 1/4"
1"	1/4" x 1 1/2"



When welding the joint, use an AWSE 6010 or AWSE 6011 electrode. Make 4 welds; CAUTION: Do not have a crater in the rod at the end of each bead.

Tie At Top of Poles

In most cases the existing ties at the top of the poles will be satisfactory. A 2x4 or 2x6 cross-tie at each pole should be adequate if it is well spiked to the poles with large pole-barn nails. Sometimes four strands of number nine wire are used as a cross-tie.

Table 145-5. Recommended size, spacing, and location of structural members—pole cribs.

Tie Rod Height	Maximum Pole Spacing (Inches)			Rod Spacing & Size					
	4' Pole	5' Pole	6' Pole	Threaded 3' o.c.	Threaded 4' o.c.	Threaded 5' o.c.	Unthreaded 3' o.c.	Unthreaded 4' o.c.	Unthreaded 5' o.c.
12'	6 1/2"	26"	48"	80"	5/8"	3/4"	3/4"	1/2"	5/8"
14'	6 1/2"	24"	42"	70"	5/8"	3/4"	7/8"	5/8"	3/4"
16'	6 1/2"	18"	32"	52"	3/4"	7/8"	1"	5/8"	3/4"
18'	7'	—	24"	40"	7/8"	1"	1"	3/4"	7/8"
20'	7'	—	18"	30"	7/8"	1"	1 1/8"	3/4"	1"

*Min. top diameter; inches
Pole and tie-rod spacing are the same.

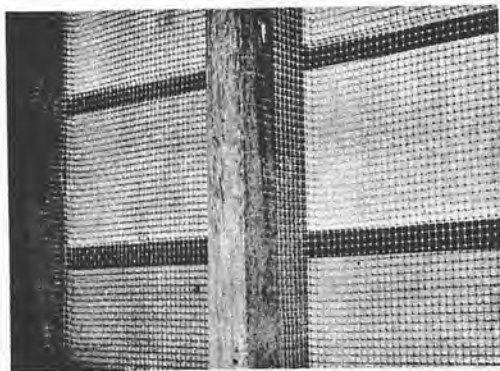
Making A Crib Grain-Tight

The experience of several farmers and universities has shown that shelled corn can be stored in cribs that are not weather-tight from harvest to the middle of the following summer. If this is the way you will process your corn, you need only make the remodeled crib grain-tight.

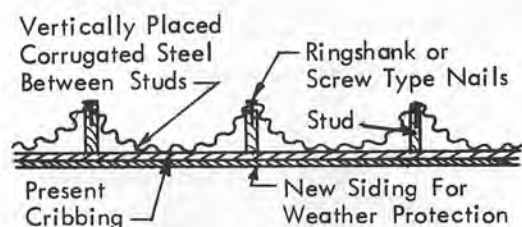
A crib designed or remodeled for this use will not work well for aeration after drying corn, or as a bin for drying wet corn. It will be difficult to fumigate the corn to control insects as the walls cannot be effectively covered with canvas or plastic.

Stud-Frame Cribs

One successful method that has been used is shown below. The best way to apply the one-quarter inch hardware cloth is to fit it between the studs, letting it rest against the inside face of the cribbing.

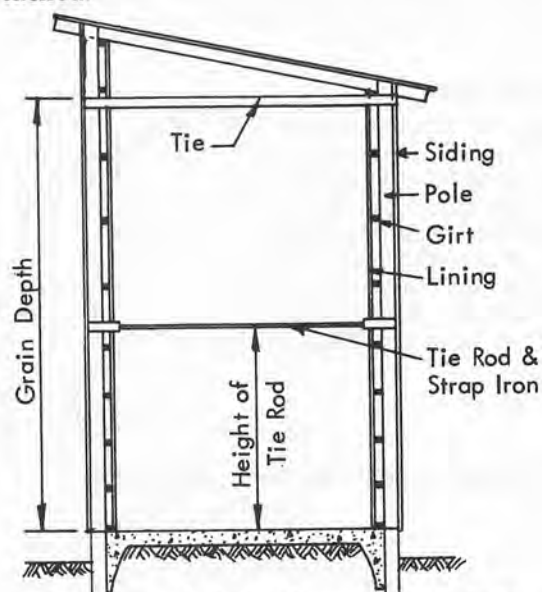


Another method of making the crib grain-tight is to place corrugated steel sheets between the studs. Fasten the sheets to the studs with ringshank or screw type nails.



Pole Cribs

The inside of the crib must be lined with material that will support the pressure of the corn. The most practical way to do this is to install girts between the poles to which a lining material is attached.



Recommended girt (support) spacings are listed in Table 145-6. Some materials do not have sufficient strength to span the recommended girt spacings in Table 145-6. The maximum spacing between supports for commonly used crib materials is listed in Table 145-7.

Table 145-6. Recommended girt spacing (inches).

Grain Depth (feet)	Pole Spacing (feet)	Girt Size		
		2x4 (Rough; flat)	2x4 (Dressed; On Edge)	2x6 (Dressed; On Edge)
8-12	3	24"	32"	--
	4	14"	18"	--
	5	--	12"	28"
12-16	3	18"	26"	--
	4	12"	16"	30"
	5	--	--	24"
16-20	3	18"	24"	--
	4	12"	28"	--
	5	--	--	20"

Table 145-7. Maximum girt spacing permitted by strength of lining material (inches).

Grain depth (feet)	Type of Lining Material					1 1/4" Corrugated steel, 28 ga.	2 1/2" Corrugated steel, 28 ga.
	3/8" ply-wood	1/2" ply-wood	5/8" ply-wood	3/4" ply-wood	1" boards		
8-12	14	18	21	24	31	15	21
12-16	13	16	19	22	28	13	19
10-20	12	15	18	20	26	13	18

Making A Crib Weather-Tight

If corn will be stored for a year or more, the crib should be made weather-tight to reduce spoilage. If the roof is in good condition and does not leak, it will not have to be altered. For most cribs, only the walls need to be altered.

A variety of methods may be used to make the crib walls weather-tight. Several are described below.

Stud-Frame Cribs

A method commonly used is to line the inside of the stud with exterior-grade plywood or matched boards of top quality. The minimum thickness of plywood is three-eighths inch for 12-inch stud spacings, one-half inch for 18-inch spacing, and five-eighths inch for 24-inch spacing.

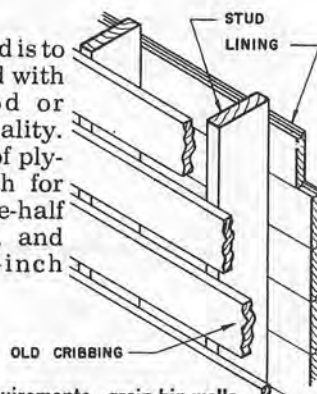
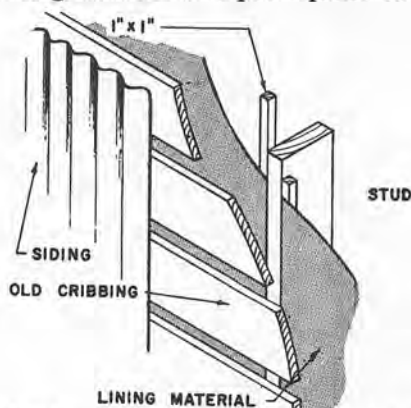


Table 145-8. Plywood thickness requirements—grain bin walls.

Stud Spacing	Depth of Fill (Shelled Corn)			
	8'	12'	16'	20'
12"	5/16"	5/16"	3/8"	1/2"
16"	3/8"	3/8"	1/2"	5/8"
20"	1/2"	1/2"	5/8"	3/4"
24"	5/8"	5/8"	3/4"	1"
32"	3/4"	1"		

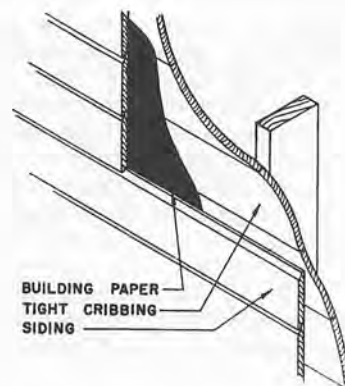
Another method of weatherproofing walls is to line the inside of the cribbing with sheet metal, moisture-resistant hardboard or other suitable material. Then cover the outside with a weather-resistant siding material.

Fit the lining between the studs. Cover any cracks with wooden strips. Fasten the cribbing to the studs with at least four eight penny screw-shank or ring shank nails per square foot of wall.

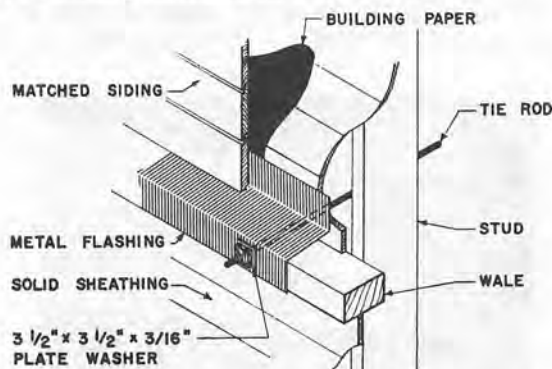


surface. Apply the siding following the manufacturer's recommendations.

Renailing cribbing and covering with siding is another method of making the walls weathertight. Cribbing that is in good condition can be removed and renailed so that no space is left between the boards. Cover the cribbing with building paper and complete the siding to form a good weathertight wall.

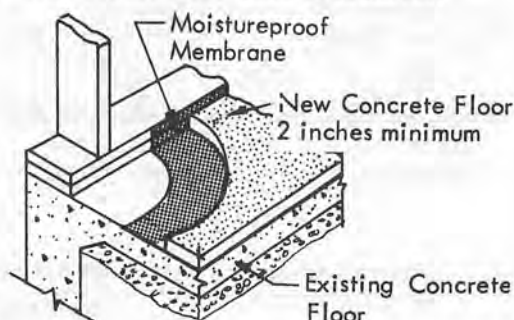


In making the walls weathertight, pay particular attention to construction adjacent to the wale. The wale should bear directly against the studs and have flashing installed as shown below.



The floor must be altered if there is any possibility that moisture will penetrate to spoil the corn. Wooden floors that are supported well above ground level will be adequately protected, but a concrete floor resting directly on the ground may need moisture proofing, especially if the crib is in a poor drainage area.

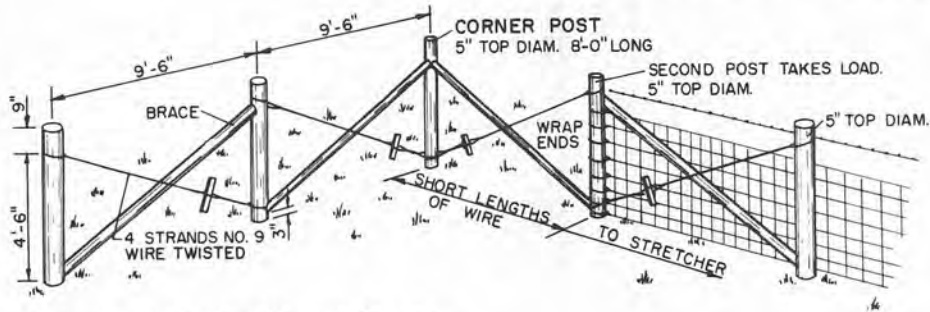
A concrete floor may be made moisture proof by applying a layer of 45-pound, smooth-surface, roll roofing, or six mil polyethylene, before covering the floor with at least two inches of concrete.



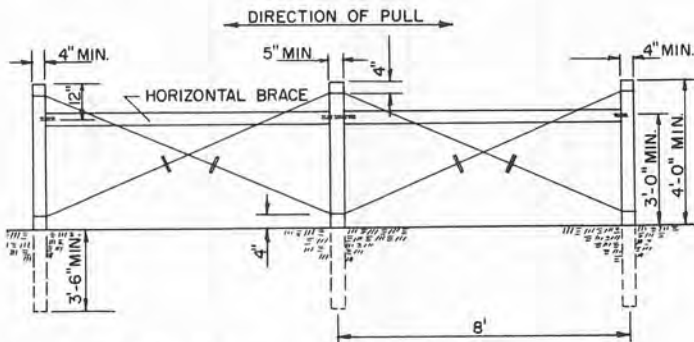
Pole Cribs

In addition to lining inside the girts, a weather-tight siding may be applied outside the poles. A lining alone will normally not be weathertight. Siding protects the girts and lining from weather damage and decay. A material like metal siding sheets can be applied horizontally directly to the poles.

CHAPTER 146 FENCE CONSTRUCTION



Corner or End—Wood Posts



Wood Pull—Post
For Middle of Long Fence, Place 40 Rods Apart

Post Sizes

End Post Min. Sizes

- 2½" x 2½" x ¼" Angle
- 2" I.D. Standard Pipe
- 5" Top Wood Post—8' Long

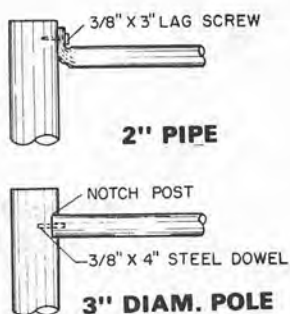
Brace Post Min. Size (Wood)

- 1st Brace Post—5" Top, 8' Long
- 2nd Brace Post—4" Top, 8' Long

Brace

- For Angle or Pipe Corner Post
 - 1¼" I.D. Standard Pipe
 - 2" x 2" x ¼" or 3/16" Angle
- For Wood Corner Posts
 - 2" I.D. Standard Pipe
 - 2" x 2" x ¼" or 3/16" Angle

Braces



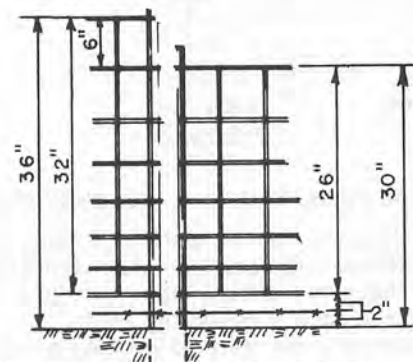
Construction Steps

This extra strong fence corner, or end, is good in soft soils, or where deadman on corner post would otherwise be necessary.

1. Set all fence posts.
2. Install bracing.
3. Fasten wire to second post.
4. Tighten from second post, and complete line fence.
5. Using short lengths of wire, close corner.

Fence Dimensions

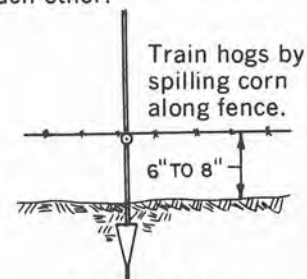
Swine



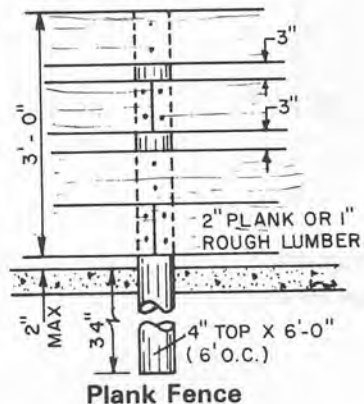
36" Fence

30" Fence

30" Fence: Can climb over. High enough for temporary fence & between pens where pigs can see each other.

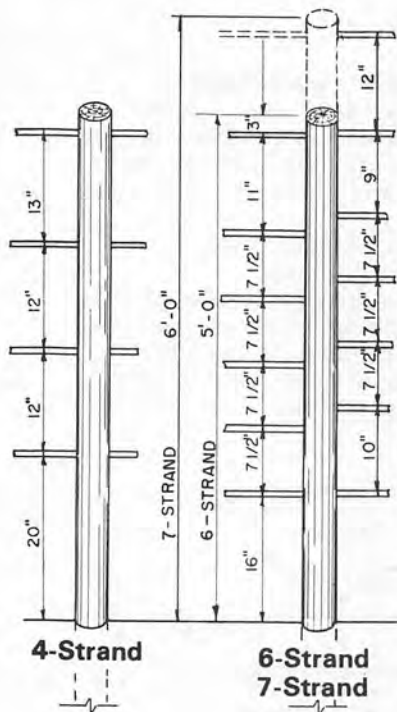


Electric Fence



Plank Fence

Beef or Dairy



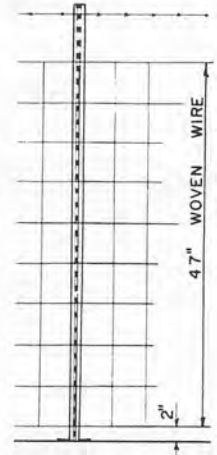
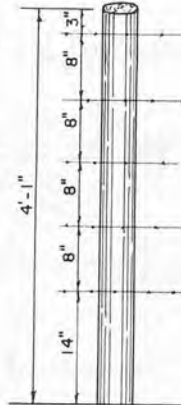
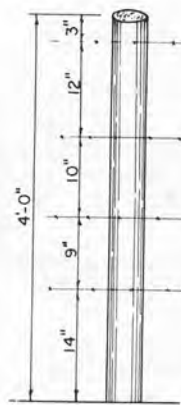
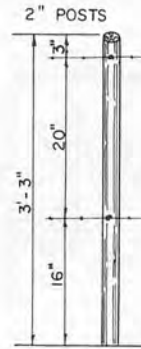
4" Top Posts, 8'-0" o.c., Set 2'-6" Deep

4-strand fence - for lot partitions and boundaries.

6-strand fence - for portions of lot fences which will have to restrain driven cattle - near gates and access to working area.

7-strand fence - for alley to working area, and lines in the working area where there will not be heavy driving - holding pen partitions and boundaries.

Use plank fences in crowding and working areas.



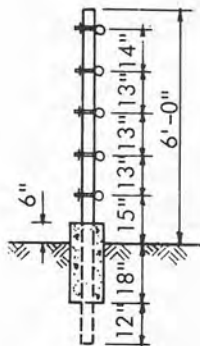
4-Wire Barbed

5-Wire Barbed

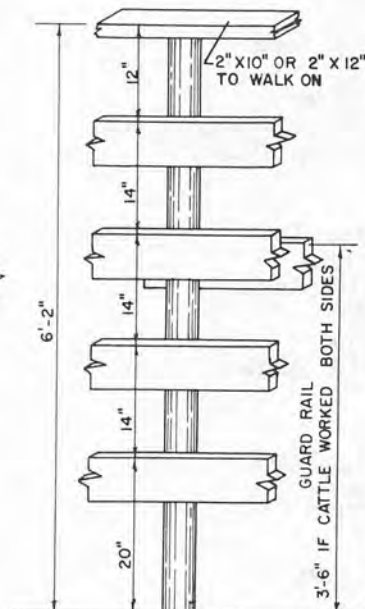
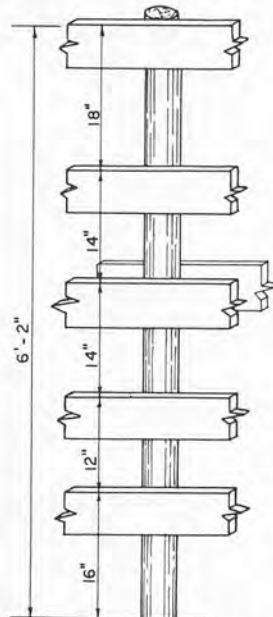
Woven Wire

**Posts: Steel or
4" Top Wood**

LINE FENCES



**Horses
Corral Fence**



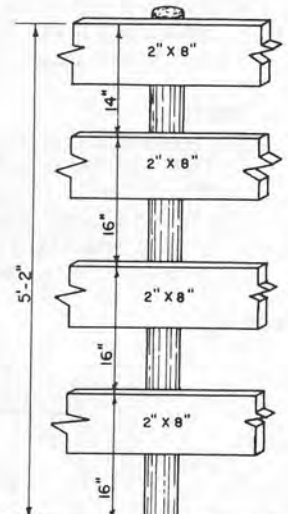
4" Top Posts 6' o.c.

2x6 plank for larger areas

2x8 plank for small and crowded areas

WORKING FENCES

Corral, Paddock, Yards, Bull Pens May Be Used For Horses



4" Top Posts 8' o.c.

**FEED LOT LINE
FENCES**

200 ENVIRONMENT

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Environment means surroundings—all those materials and conditions that surround and affect us. In livestock housing, environmental control includes more than ventilation or temperature moderation. It includes feed and water, and their quality, quantity, and availability. It includes building surfaces, and their temperature, roughness, wetness, and cleanliness. It can include noise and other stress-producing influences. Waste management, health care, and accident-free facilities and management are also part of an animal's environment. In crop production, environment includes handling methods; building type and construction; and drying, curing, or processing systems; and the effects of these factors on quality.

Ventilation—the method of environmental modification most often considered for agricultural structures—is more than just pushing or pulling air through a building space or a pile of grain. Climate (long term, average weather conditions) and weather (today's temperature or rainfall) determine the properties of outdoor air used in ventilation. Indoor conditions are determined by the housed animals or stored crops; weather; building type and construction; equipment for ventilating, heating, or cooling, and their management; and systems for handling feed, water, wastes, and produced products (eggs, milk), and their management.

210 FUNDAMENTALS

CHAPTER 211 ANIMAL THERMAL ENVIRONMENT

An animal's environment is the total of all external conditions that affect it. In this chapter, thermal environment is considered. It concerns heat transfer: the climatic factors of air temperature, moisture, air velocity, and solar radiation that affect the regulation and balance of animal heat and that influence production, growth, feed conversion, and health.

Definitions

Heat is a form of energy transferred from one body to another at lower temperature, because of the temperature difference.

Temperature is a measure of a body's ability to transfer or receive heat from matter in contact with it or from surrounding surfaces.

The Fahrenheit scale was developed with 0°F as the minimum temperature of an ice and salt mixture, 32°F as the freezing point of water, and 212°F as the boiling point of water. On the Celsius scale, 0°C is the freezing point, and 100°C is the boiling point, of water. The relationship between the two temperature scales is

$$t_F = 1.8 t_C + 32 \quad \text{Eq 211-1}$$

or

$$t_C = \frac{t_F - 32}{1.8}$$

The Rankine (absolute Fahrenheit) and Kelvin (absolute Celsius) scales are based on the point at which the pressure of gas is zero.

$$T_R = t_F + 460^\circ\text{F} \quad T_K = t_C + 273^\circ\text{C} \quad \text{Eq 211-2}$$

Ambient Temperature is the temperature of the medium surrounding a body or system; for example, room air temperature.

Quantity of heat is measured in British thermal units (Btu); 1 Btu raises the temperature of 1 lb of water at atmospheric pressure 1°F at a temperature of 59°F. For the energy value of feed, one kilocalorie (kcal) raises 1 kg of water 1°C. One kilocalorie = 3.968 Btu.

Specific heat capacity of a material is the quantity of heat supplied per unit weight of the material to increase its temperature 1 degree; units are Btu/lb-°F or kcal/kg-°C.

Sensible heat is a measure of the energy that accompanies a temperature change:

$$q_s = M c (t_1 - t_2) \quad \text{Eq 211-3}$$

where:

$$\begin{aligned} q_s &= \text{total sensible heat, Btu} \\ M &= \text{weight of material, lbs} \\ c &= \text{specific heat of the material, Btu/lb-°F} \\ t_1 \text{ \& } t_2 &= \text{temperature of material at conditions 1 and 2 respectively, °F.} \end{aligned}$$

Latent heat is required or released when a material changes phase without a change in temperature. The three phases are solid, liquid, and gas. Latent heat of fusion is required for a solid-liquid phase change. For example when ice melts or water freezes, 144 Btu/lb is absorbed or released without a change in temperature. Latent heat of vaporization is required for a liquid-gas phase change. If one pound of water at 100°F is changed from a liquid to vapor at standard pressure, 1036 Btu must be supplied; see Table 211-1.

Table 211-1. Latent Heat of Vaporization of Water at Standard Atmospheric Pressure

Temperature, °F	Latent Heat, Btu/lb
32	1076
40	1071
60	1061
80	1048
100	1036
120	1025
140	1013
160	1001
180	990
200	978
212	970

As a gas cools it returns to the liquid phase, or condenses, and gives up the same amount of heat required to vaporize it. The heat of condensation lost per unit weight equals the heat of vaporization. The sensible and latent heat for water to change phase and temperature are shown in Fig 211-1.

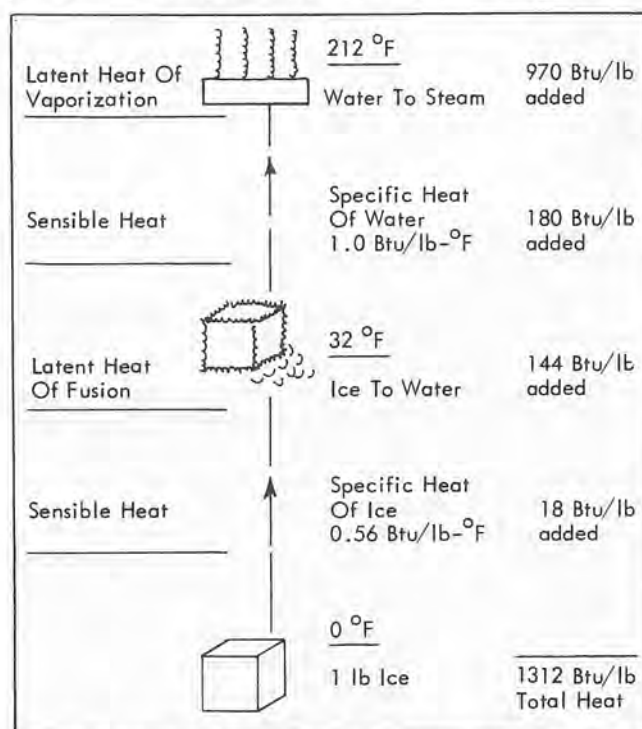


Fig 211-1. Sensible and latent heat to change 1 lb of ice at 0°F to vapor at 212°F.

Mechanical Equivalent of Heat. From experiments, 778 ft-lb of mechanical energy, when converted to heat, raises the temperature of 1 lb of water 1°F, or equals 1 Btu of heat. Other useful conversions from power to heat are:

$$1 \text{ hp-hr} = 2545 \text{ Btu}$$

$$1 \text{ kw-hr} = 3413 \text{ Btu}$$

Quantity of Refrigeration. Refrigeration systems are rated in Btu per hr, or tons; one ton of refrigeration is the latent heat of fusion of 1 ton of ice melted in 24 hr, (288,000 Btu/24 hr or 12,000 Btu/hr).

Homeothermic Systems

Livestock and poultry are **homeothermic**—they maintain a relatively constant body temperature.

Temperature regulation is an example of **homeostasis**, the maintenance of a bodily state within narrow limits. Small corrections in body temperature are controlled by the **hypothalamus gland** (Fig 211-2), which acts as a very accurate thermostat. The hypothalamus regulates body temperature by detecting internal body temperature, integrating it with neural signals from thermoreceptors at the skin surface, and then controlling neural and hormonal responses that alter heat production or heat loss.

Livestock and poultry have complex chemical and physical controls, Fig 211-2, that maintain a nearly constant internal body temperature over a range of climatic conditions; an increase in body temperature of only a few degrees can be fatal. Table 211-2.

Table 211-2. Normal rectal temperatures.

Animal	Temperatures	
	Average	Range
Dairy Cow	101.5°F	100.4 - 102.8°F
Beef Cow	101.0	98.0 - 102.4
Pig	102.5	101.6 - 103.6
Sheep	102.3	100.9 - 103.8
Chicken	107.1	105.0 - 109.4

Internal body temperature is controlled by a dynamic equilibrium between heat produced internally and heat gained from or lost to the environment. The animal produces heat when transforming chemical energy of feed into work. In its simplest form the thermal balance is:

$$\text{Heat production} = \pm \text{heat loss} \pm \text{heat storage}$$

The rate of internal heat production varies with size, body weight, breed, health, stage of growth, nature and rate of feed intake, level of production, gestation, age, degree of activity, and environmental conditions. Of the gross feed-energy consumed by an animal in production, 25% - 40% is converted into heat and lost to the environment. Animal performance is greatly affected by heat exchanged between it and the environment. In a cold environment where heat loss is greater than normal heat production, net energy normally used for growth and production is used for heat, resulting in decreased performance.

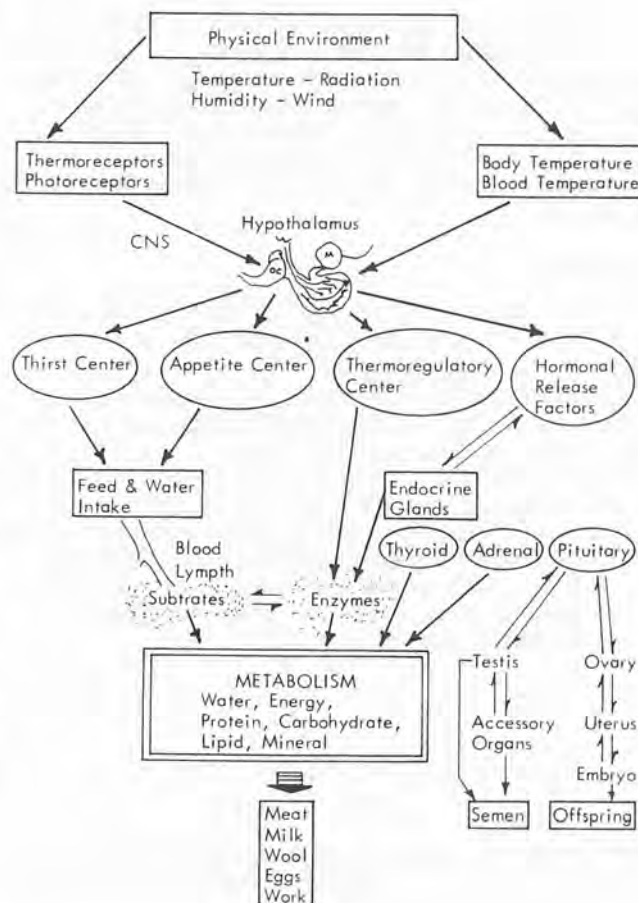


Fig 211-2. Interactions between physical environment and animal productivity.

Methods of Heat Transfer

The total heat exchanged hourly between an animal and its surroundings, q_T , consists of both sensible, q_s , and latent heat, q_l . Sensible heat transfer is governed by the mechanisms of heat transmission: conduction, convection, and radiation. All animals dissipate significant amounts of latent heat by vaporization, or moisture evaporation, from the respiratory tract, lungs, and body surface. The total heat exchange between animal and environment is:

$$q_T = q_l \pm q_s = q_e \pm q_r \pm q_c \pm q_d \quad \text{Btu/hr}$$

where:

$$\begin{aligned} q_e &= \text{evaporation} \\ q_r &= \text{radiation} \\ q_c &= \text{convection} \\ q_d &= \text{conduction} \end{aligned}$$

Eq 211-4

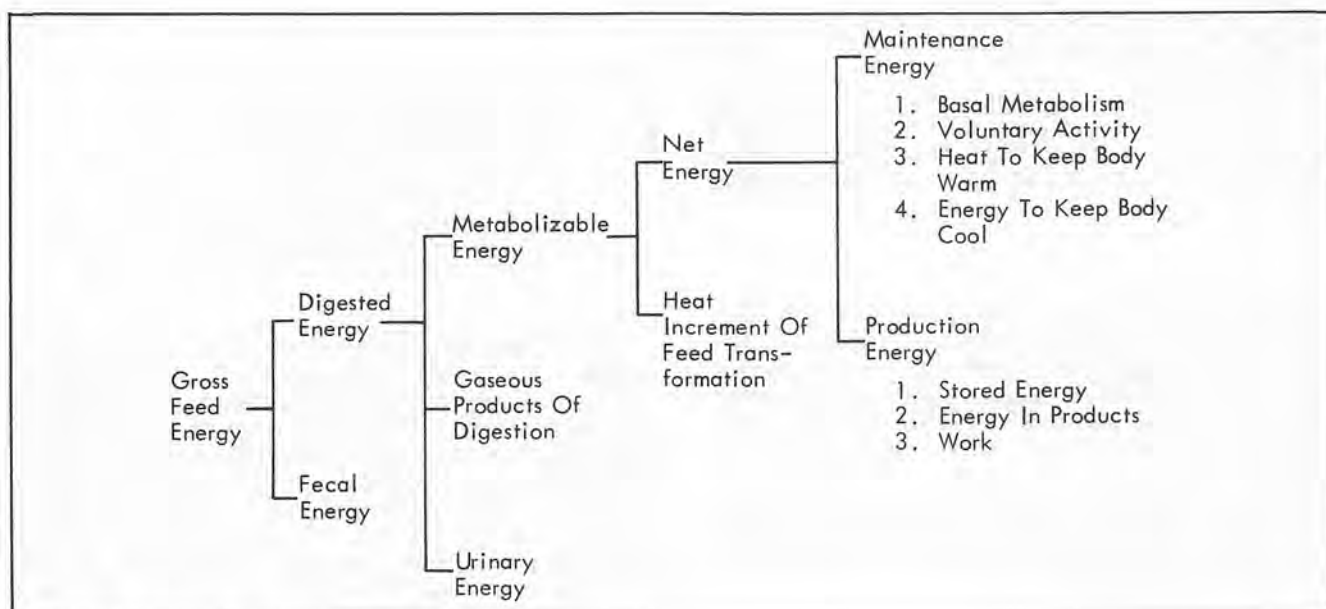


Fig 211-3. Feed energy utilization in animals.

In Eq 211-4 sensible heat is positive if heat is transferred from the animal. Where ambient temperature is greater than the surface temperature of the animal, sensible heat is gained by the animal and the terms are negative.

Conduction is heat transfer between bodies in direct contact, because of a temperature difference, and without gross movement of the material. Internal body conduction is moving heat from inside the body to its surface, although heat movement by the blood is convection. More important is conductive transfer from the skin to adjacent surfaces—floor, bedding, or another animal. The relationship for conduction heat transfer is:

$$q_d = UA (t_{sa} - t_{se}) \quad \text{Eq 211-5}$$

where:

- q_d = heat transfer by conduction, Btu/hr.
- U = conductive heat transfer coefficient between the animal and the environment, Btu/hr-sq ft-°F.
- A = contact area for conductive heat flow, sq ft.
- t_{sa} = surface temperature of the animal, °F.
- t_{se} = surface temperature of the material in contact with the animal, °F.

Many animals adjust conductive heat loss simply by changing contact area—huddling with a warm animal, standing up from a cold floor.

Convective heat exchange occurs when particles of a fluid mix with lower or higher temperature particles. Natural or free convection may result from differences of density caused by temperature differences. Fans, pumps (including the heart) or blowers produce fluid motion and heat transfer known as forced convection.

The rate of heat exchange by convection is:

$$q_c = H_c A_c V^n (t_{sa} - t_a) \quad \text{Eq 211-6}$$

where:

- q_c = heat transferred by convection, Btu/hr.
- H_c = convection coefficient.
- A_c = effective convective surface, sq ft.
- V = air velocity, fpm.
- n = velocity exponent
- t_{sa} = surface temperature of the animal, °F.
- t_a = ambient air temperature, °F.

Values for H_c and n have not been widely determined for livestock, but, the form of the equation shows the important variables. The combined effect of high air velocity and cold ambient temperature results in high heat loss from livestock. When ambient air temperature equals the body's surface temperature, convective heat transfer from the skin is zero.

Thermal Radiation is the exchange of thermal energy between objects by electromagnetic waves. The rate depends upon their temperatures and the nature of their surfaces. Radiation can pass through a vacuum. It warms the receiving (cooler) body.

The radiant heat transfer equation is:

$$q_r = A F_a F_e S (T_{sa}^4 - T_s^4) \quad \text{Eq 211-7}$$

where:

- q_r = rate of radiant heat transfer, Btu/hr.
- A = area of radiating object, sq ft.
- F_a, F_e = shape and emissivity factors
- S = Stefan-Boltzman constant, 0.174×10^{-8} , Btu/sq ft-hr-°R⁴
- T_s, T_{sa} = absolute temperature (°t_F + 460) of the surroundings and animal surface, °R.

The evaluation of F_a and F_c is complicated and detailed; some livestock shelter configurations have been developed.

The surroundings include the sun, sky, shade, fences, buildings or other animals—any object or surface that an animal can “see”. Sun radiant heat load can be reduced 30% - 50% with shade.

Evaporation: Moisture loss through the skin surface is minimal in most domestic animals (cattle, swine, sheep, poultry); evaporative loss is largely from their respiratory tracts. Expired air, heated nearly to body temperature and saturated with water vapor, is exhaled as liquid water vaporized in the lungs.

Nonsweating species adjust to high temperature stress by greatly increased respiration—panting. Animal skin surfaces are wetted to maximize cooling by external evaporation.

The evaporation heat transfer equation is:

$$q_e = K_e A_e V^n (P_s - P_a)$$

Eq 211-8

where:

q_e = evaporation heat loss, Btu/hr.

K_e = evaporation constant

A_e = wet surface area of the animal, sq ft.

V = air velocity, fpm.

n = velocity exponent

P_s = vapor pressure of water at the animal's internal or external surface, psi.

P_a = vapor pressure of water in the air.

Total heat production from farm animals is in two forms: sensible heat, transferred by conduction, convection and radiation; and latent heat transferred by evaporation of moisture from lungs and body surfaces. Sensible heat is transferred because of a temperature difference, while latent heat is a measure of the animal's water vapor production.

Homeothermic animals maintain nearly constant body temperature by balancing internal heat production and heat loss to the surroundings. The factors involved are illustrated in Fig 211-4 and -5.

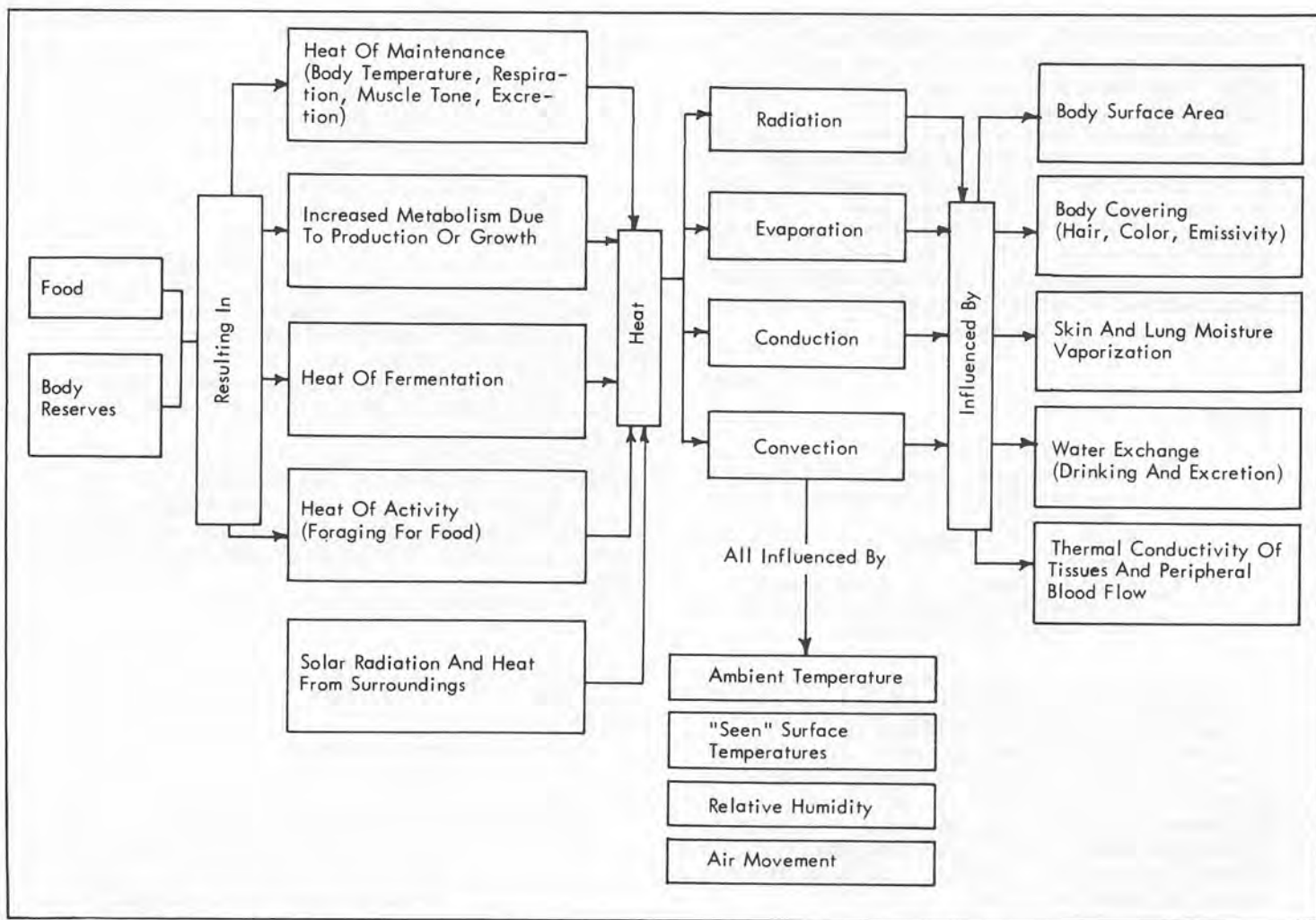


Fig 211-4. Factors Influencing Heat Balance for Homeothermic Animals.

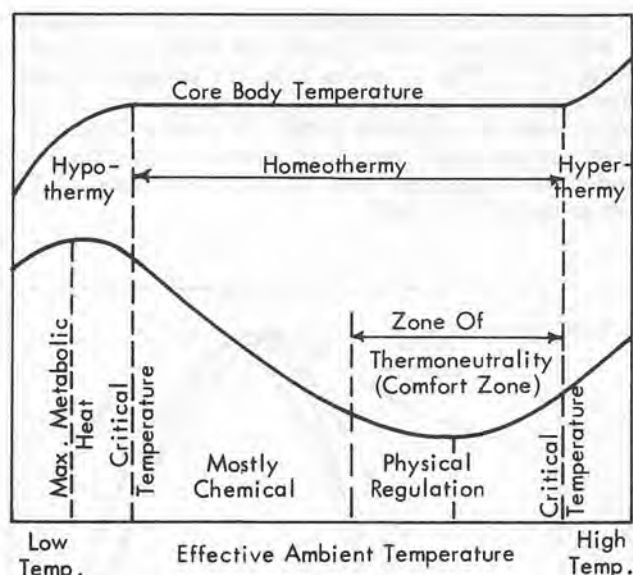


Fig 211-5. Heat production and body temperature of homeotherms vs ambient temperature.

In the zone of thermo-neutrality, or the comfort zone, an animal maintains its homeothermic state automatically by physical means, by losing heat to the environment, and attains maximum productivity.

Effective temperature includes dry bulb and wet bulb temperatures, and air movement. As it falls below the comfort zone, the animal increases metabolic heat production to compensate for body heat loss. At the lower critical temperature, metabolic heat can no longer cope with excessive heat loss and body temperature begins to drop. Metabolic heat continues to increase until its maximum is reached. Further decline of the ambient temperature breaks down the mechanisms of homeothermy, and both heat production and body temperature decline.

As the effective temperature rises above the comfort zone, the upper critical temperature is quickly reached, and body temperature starts to climb.

Livestock heat production

A general equation developed by Brody estimates basal heat production of most homeotherms:

$$q_b = KW^{0.734} \quad \text{Eq 211-9}$$

where:

q_b = basal heat production, Btu/hr.
 K = coefficient
 W = animal weight, lb.

By properly estimating K , the total heat production, q_t , of the animal can be approximated for the thermal comfort zone. Brody found K to be about 6.5 for the basal condition. For normal activity, K is about $2\frac{1}{2}$ times basal, 16.25. The equation does not relate heat production and ambient tem-

perature. The empirical exponent, 0.734, compares to the geometrical relation that surface area (L^2) is dimensionally the $2/3$ power of volume (L^3). In a uniformly dense body, weight is also directly proportional to volume.

The ratio of surface area to animal body weight varies considerably, decreasing as weight increases. For example, the surface area of a 4-lb chicken is about 1.9 ft², a surface/weight ratio of 0.48; for a 1000-lb cow with 49.5 ft² surface, the ratio is 0.05.

Since heat production is a function of body weight and metabolism, and heat transfer from an animal depends largely on surface area, heat transfer per unit weight is higher for smaller animals. Fig 211-6.

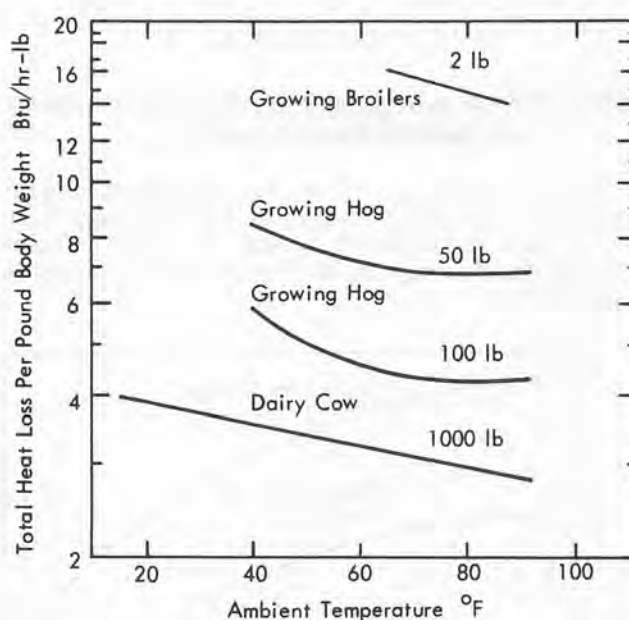


Fig 211-6. Effect of ambient temperature on total heat loss.

Air temperature and livestock production efficiency

Air temperature is the only climatic element that affects directly all four methods of heat transfer. Fig 211-7 relates the proportions of latent and sensible heat production to air temperature for several farm animals.

At high temperatures heat transfer by conduction, convection and radiation is reduced and excess heat is eliminated by moisture evaporation from lungs. In addition to behavioral vasomotor, hormonal, and respiratory responses to increasing heat stress, the animal reduces feed intake, which decreases the amount of heat to be dissipated. A production decrease results from reduced energy intake.

At low temperatures heat released from feed may not balance increased heat loss, so some food energy supplies body heat instead of growth or production.

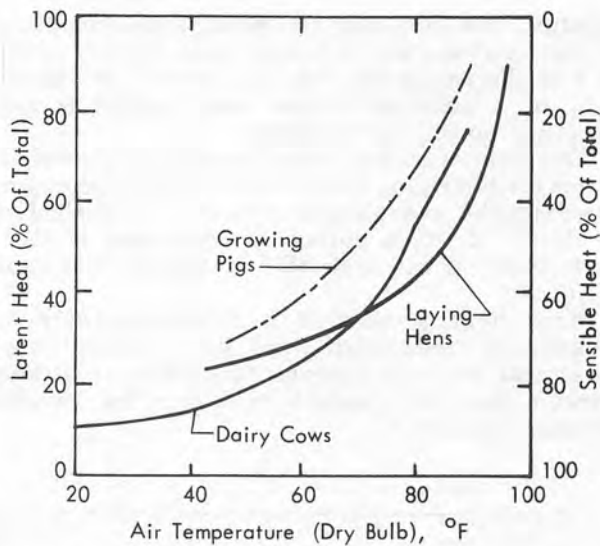


Fig 211-7. Effect of air temperature on relative latent and sensible heat production of livestock and poultry.

The temperature range for maximum animal production efficiency is shown on the lower part of Fig 211-8. Between t_1 and t_2 is the thermal comfort zone, where production efficiency changes only slightly.

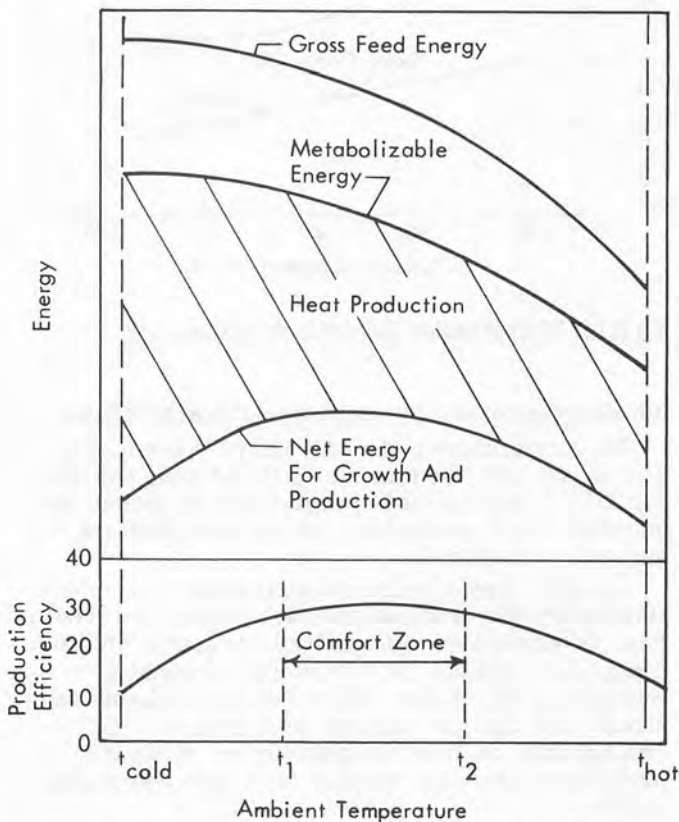


Fig 211-8. Influence of air temperature on the proportion of food energy available for production.

The effect of air temperature on the productivity of some classes of livestock and poultry is shown in Fig 211-9. The optimum temperature zone varies with type and age of animal, changes in air velocity, and to a lesser extent, relative humidity. Most temperature response data are observed at moderate humidity, and at air velocities of 50 fpm or less ("still" air).

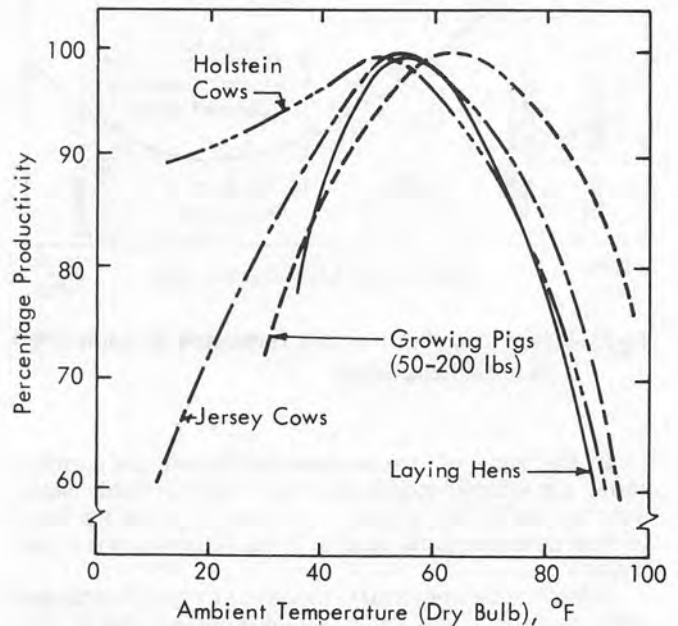


Fig 211-9. Effect of air temperature on percentage productivity of livestock and poultry.

CHAPTER 212 AIR-WATER VAPOR MIXTURES—PSYCHROMETRICS

The earth's atmosphere is a mixture of gases and water vapor. The composition of dry air adopted by the International Joint Committee on Psychrometric Data is given in Table 212-1. An understanding of physical and thermodynamic properties of air-water vapor mixtures—psychrometrics—is fundamental to the design of environmental control systems for plants, crops, animals, or humans.

Table 212-1. Composition of dry air.

Gas	Molecular Weight		Mole-Fraction Composition		Partial Molecular Weight
Oxygen (O ₂)	32.000	x	0.2095	=	6.704
Nitrogen (N ₂)	28.016	x	0.7809	=	21.878
Argon (A)	39.944	x	0.0093	=	0.371
Carbon Dioxide (CO ₂)	44.01	x	0.0003	=	0.013
					28.966

Properties of Moist Air

Pressure, volume, weight and thermal properties are related by laws developed for a "perfect" gas, but applied to air-water vapor mixtures for solving environmental control problems.

Perfect Gas Law. The thermodynamic state of moist air is established by pressure and two other independent properties. But most psychrometric charts are for a constant pressure, and only the two other independent properties are used. The relationship between the properties of a perfect gas is:

$$PV = M R T \quad \text{Eq 212-1}$$

$$\text{or } P = M R T / V; \quad M = PV/RT$$

where:

$$\begin{aligned} P &= \text{absolute pressure, lb/ft}^2 \\ V &= \text{volume, ft}^3 \\ M &= \text{mass, lb} \\ R &= \text{gas constant, ft lb/lb-}^\circ\text{R} \\ T &= \text{absolute temperature, }^\circ\text{R } (^\circ\text{F} + 460) \end{aligned}$$

The gas constant for air, $R_a = 53.35 \text{ ft lb/lb-}^\circ\text{R}$, and the gas constant of water vapor, $R_w = 85.78 \text{ ft lb/lb-}^\circ\text{R}$, are functionally accurate for ventilation temperatures and pressures.

Dalton's Law states that each component in a mixture of gases exerts its own partial pressure; for a mixture of air, a, and water vapor, w:

$$P = P_a + P_w \quad \text{Eq 212-2}$$

$$= \frac{M_a R_a T_a}{V_a} + \frac{M_w R_w T_w}{V_w}$$

Assuming each component gas is uniformly diffused throughout the mixture, both components have the same volume and temperature, and Eq 212-2 becomes

$$P = \frac{T}{V} (M_a R_a + M_w R_w) \quad \text{Eq 212-3}$$

Since the volume and temperature of the mixture are equal, from Eq 212-1 the following can be written:

$$\frac{P_w/V}{P_a/V} = \frac{M_w R_w T}{M_a R_a T} \quad \text{Eq 212-4}$$

$$\frac{P_w}{P_a} = \frac{M_w R_w}{M_a R_a}$$

Partial pressures may be calculated from total pressure and the weight of water vapor.

Specific Humidity, W, is the weight of water vapor in lb/lb of dry air or gr/lb da (7000 grains = 1 lb.). Other names for W include absolute humidity and humidity ratio. The base of one pound of dry air is constant for any change of condition, making calculations easier.

From Eq 212, $M = PV/RT$, and Dalton's Law, specific humidity for an air-water vapor mixture can be written:

$$W = \frac{M_w}{M_a} = \frac{P_w V}{R_w T} \div \frac{P_a V}{R_a T} \quad \text{Eq 212-5}$$

$$= \frac{P_w R_a}{P_a R_w} = \frac{P_w R_a}{(P - P_w) R_w}$$

Substituting numerical values for the gas constants ($R_a/R_w = 53.35/85.78$), specific humidity becomes

$$W = \frac{M_w}{M_a} = 0.622 \frac{P_w}{P - P_w}$$

where:

$$\begin{aligned} M_w &= \text{mass of water vapor in the mixture} \\ M_a &= \text{mass of air} \end{aligned}$$

Relative Humidity, RH or ϕ , is the ratio of the actual water vapor pressure, P_w , to the vapor pressure of saturated air at the same temperature, $P_{w,s}$.

Relative humidity expressed as a percent is:

$$\text{RH\%} = 100 P_w / P_{w,s} \quad \text{Eq 212-6}$$

Vapor pressures at saturation, $P_{w,s}$, are in standard steam tables.

Specific Volume of a gas or mixture is the space occupied by a given mass. In air-conditioning work

*This chapter is from material prepared by Dr. Duane Mangold, Iowa State University

the volume is cubic feet of mixture per pound of dry air. The base of one pound of dry air is again used because the pounds of dry air entering and leaving an air-conditioning unit in a given time are constant after steady-state flow is established.

Standard air at atmospheric pressure of 14.7 psia, 70°F, and zero water vapor content, has a specific volume of 13.34 ft³/lb da. Specific volume increases as temperature or water vapor content increases.

The volume, V , of moist air per pound of dry air is calculated from:

$$V = V_a + \mu V_{as} \quad \text{Eq 212-7}$$

where:

V = specific volume of dry air, ft³/lb da.

V_s^a = volume of moist air at saturation per pound of dry air, ft³/lb da.

$V_{as} = V_s - V_a$

μ = degree of saturation, the ratio of the specific humidity of moist air to the specific humidity of saturated air at the same dry-bulb temperature and pressure.

The thermodynamic properties of moist air, Table 212-2 by Goff and Gratch, can be used in Eq 212-7 to calculate volume.

Table 212-2. Thermodynamic Properties of Air-Water Vapor Mixtures.

Fahr. Temp. t (F)	Satura- tion Vapor Pres. lb/in ²	Weight of Vapor per lb Dry Air		Volume, ft ³ /lb Dry Air†			Enthalpy, Btu/lb Dry Air‡		
		lb x 10 ²	Grains	V_a	$V_s - V_a$	V_s	h_a	h_w	$h_a + h_w$
- 20	0.006	0.026	2	11.07	0.00	11.08	- 4.80	0.28	- 4.52
- 15	0.008	0.035	2	11.20	0.01	11.21	- 3.60	0.37	- 3.23
- 10	0.011	0.046	3	11.33	0.01	11.34	- 2.40	0.49	- 1.91
- 5	0.014	0.060	4	11.45	0.01	11.46	- 1.20	0.64	- 0.56
0	0.018	0.079	6	11.58	0.02	11.60	0.00	0.84	0.84
5	0.024	0.102	7	11.70	0.02	11.72	1.20	1.08	2.28
10	0.031	0.132	9	11.83	0.02	11.85	2.40	1.40	3.80
15	0.040	0.169	12	11.96	0.03	11.99	3.60	1.80	5.40
20	0.050	0.215	15	12.08	0.04	12.12	4.80	2.30	7.10
25	0.064	0.273	19	12.22	0.05	12.27	6.00	2.93	8.93
30	0.081	0.345	24	12.34	0.07	12.41	7.21	3.71	10.92
35	0.100	0.428	30	12.46	0.08	12.54	8.41	4.60	13.00
40	0.122	0.521	37	12.59	0.10	12.69	9.61	5.62	15.23
45	0.148	0.633	44	12.72	0.13	12.85	10.81	6.84	17.65
50	0.178	0.766	53	12.84	0.16	13.00	12.01	8.29	20.30
55	0.214	0.923	64	12.97	0.19	13.16	13.21	10.01	23.22
60	0.256	1.108	77	13.10	0.23	13.33	14.41	12.05	26.46
65	0.306	1.326	92	13.22	0.28	13.50	15.61	14.45	30.06
70	0.363	1.582	110	13.35	0.34	13.69	16.82	17.27	34.09
75	0.430	1.882	131	13.47	0.41	13.88	18.02	20.59	38.61
80	0.507	2.233	156	13.60	0.49	14.09	19.22	24.47	43.69
85	0.596	2.642	184	13.73	0.58	14.31	20.42	29.01	49.43
90	0.698	3.118	217	13.85	0.69	14.54	21.62	34.31	55.93
95	0.816	3.673	256	13.98	0.82	14.80	22.83	40.49	63.32
100	0.950	4.319	300	14.11	0.98	15.09	24.03	47.70	71.73
105	1.102	5.070	353	14.23	1.16	15.39	25.23	56.11	81.34
110	1.275	5.944	413	14.36	1.36	15.72	26.43	65.91	92.34
115	1.472	6.962	484	14.48	1.61	16.09	27.64	77.34	104.98
120	1.693	8.149	566	14.61	1.90	16.51	28.84	90.70	119.54

*Abstracted from ASHRAE Handbook of Fundamentals, 1972, Table 1 of Chapter 32. (Data compiled by John A. Goff and S. Gratch).

† V_a = specific volume 1 lb dry air; V_s = specific volume saturated air-vapor mixture per pound of dry air.

‡ h_a = enthalpy, 1 lb dry air; h_w = enthalpy of vapor in a saturated mixture containing 1 lb dry air.

Temperature. Three different temperatures describe an air-water vapor mixture: dry-bulb, db, wet-bulb, wb, and dewpoint, dp, temperatures. Dry-bulb temperature is usually measured with a common thermometer or thermocouple.

Wet-bulb temperature is measured with a common mercury thermometer or thermocouple, with the bulb or junction covered with a water-moistened wick and in a moving stream of ambient air. Evaporation from the wick attains a steady state, in which sensible heat from the surroundings provides heat of vaporization. Air flow past the bulb is high enough to prevent significant change in the ambient air temperature. Evaporation of water cools the bulb; the drier the surrounding air the greater the rate of evaporation and the lower the wet-bulb temperature.

Wet-bulb depression is the difference between dry-bulb and wet-bulb temperatures.

Dewpoint temperature is the temperature at which moisture starts to condense from air cooled at constant pressure and specific humidity. Dewpoint temperature can be determined by bringing moist air into contact with a polished metal surface whose temperature can be both controlled and measured. As the metal surface is slowly cooled, the mixture in contact with it is also cooled. When the mixture reaches its dewpoint temperature the metal surface becomes fogged.

Enthalpy is the heat energy content of an air-water vapor mixture. Table 212-2 gives enthalpy values for dry air and water vapor. The energy is both sensible heat (indicated by dry-bulb temperature) and latent heat of vaporization (energy content of the water vapor). For convenience in air-conditioning problems enthalpy is expressed as Btu/lb da. Measures of heat content are not necessarily absolute. It is convenient to express heat content as a difference in energy between a fixed condition or datum and the condition being considered. The usual datum for dry air is 0°F and for water is 32°F.

The enthalpy, h Btu/lb da, of an air-vapor mixture can be calculated from:

$$h = c_p t_{db} + W h_{wv} \quad \text{Eq 212-8a}$$

where:

$$\begin{aligned} c_p &= \text{specific heat of dry air, 0.24 Btu/lb-°F} \\ h_{wv} &= \text{enthalpy of water vapor, Btu/lb water vapor} \end{aligned}$$

or:

$$h = 0.24 t_{db} + W(1061 + 0.444 t_{db}) \quad \text{Eq 212-8b}$$

where:

$$\begin{aligned} 1061 &= \text{latent heat of vaporization} \\ 0.444 &= \text{specific heat of water vapor} \end{aligned}$$

Adiabatic Saturation Process. An adiabatic system is perfectly insulated; no heat is added or removed externally. Unsaturated air placed in an adiabatic container and exposed to a water surface becomes saturated by evaporation. If the initial

and final water temperatures and the final air temperature are all the same, then all the heat of vaporization comes from the sensible heat of the air. The final temperature of the saturated air is the thermodynamic wet-bulb temperature.

Fig 212-1 illustrates an adiabatic process between states 1 and 2.

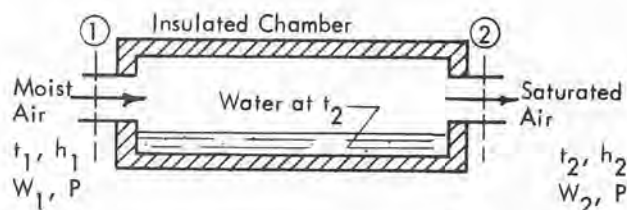


Fig 212-1. Adiabatic saturation of moist air.

The heat balance for one pound of dry air is:

$$h_2 = h_1 + (W_2 - W_1) h_{w,2} \quad \text{Eq 212-9}$$

where:

$$\begin{aligned} h_1 &= \text{enthalpy of air, state 1, Btu/lb da} \\ h_2 &= \text{enthalpy of saturated air, state 2, Btu/lb da} \\ W_1 &= \text{specific humidity of air, state 1, lb/lb da} \\ W_2 &= \text{specific humidity of saturated air, state 2, lb/lb da} \\ h_{w,2} &= \text{enthalpy of liquid water at } t_2, \text{ Btu/lb.} \end{aligned}$$

Enthalpy at saturation, h_2 , is greater than the enthalpy of the entering air, h_1 , by the small heat content of the water added, $(W_2 - W_1) h_{w,2}$. Below 110°F, insignificant error results from assuming adiabatic saturation processes are at constant wet-bulb temperature and enthalpy.

Psychrometric Chart

A psychrometric chart, Fig 212-2, presents physical and thermal properties of moist air. It enables an engineer to quickly trace changes in air properties through the various air conditioning processes. Charts for air conditioning are at standard atmospheric pressure, 29.92 in. Hg = 14.7 psia.

Properties on Psychrometric Charts. Coordinates of the charts are dry-bulb temperature along the x-axis, and moisture content or specific humidity on the y-axis. Other properties of moist air are, Fig 212-3, wet-bulb temperature, enthalpy, dewpoint temperature, relative humidity, and volume. The intersection of any two property lines establishes a given state, and all other properties can be read.

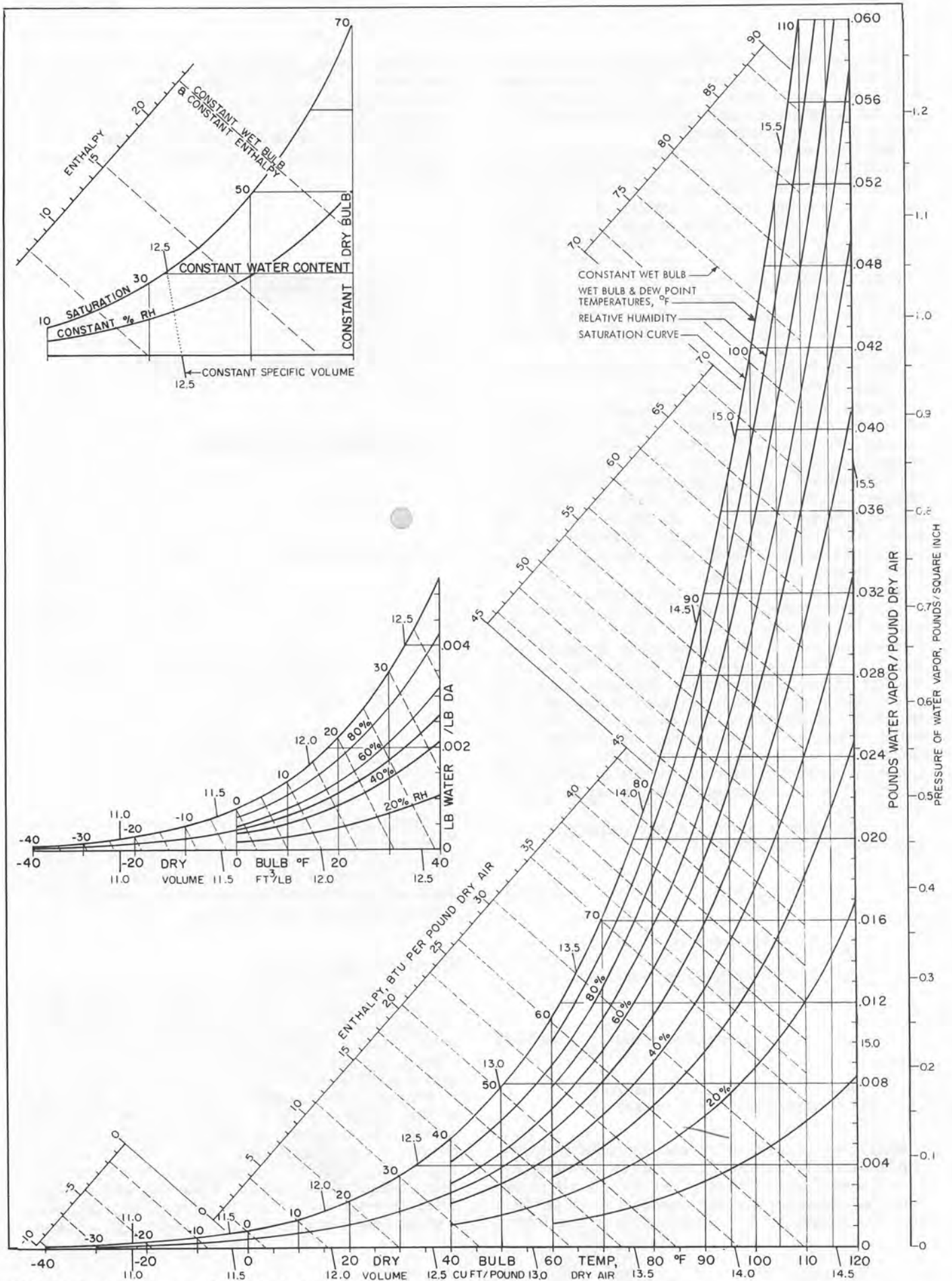


Fig 212-2. Ventilation-range psychrometric chart.

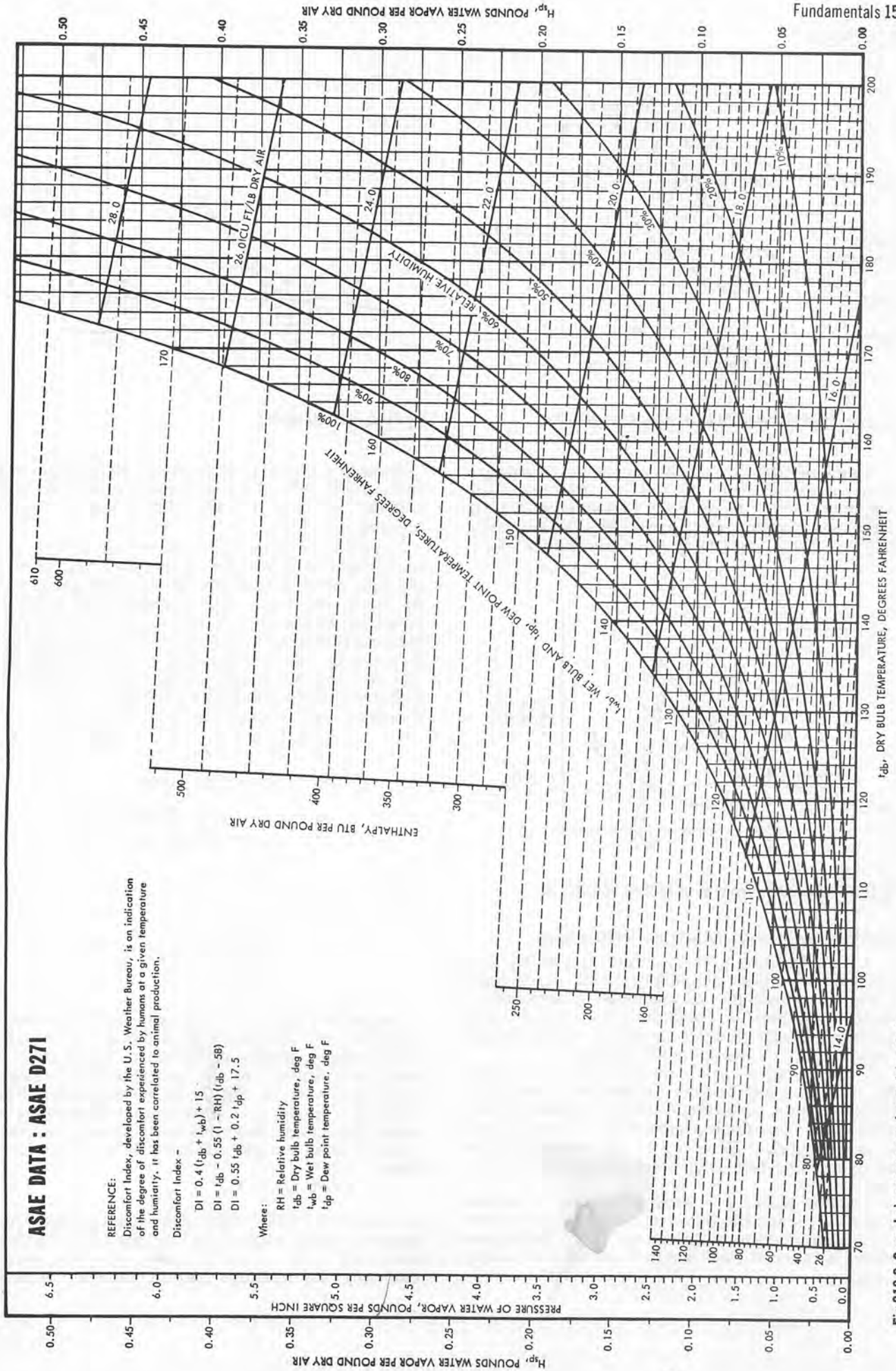


Fig 212-3. Crop-drying-range psychrometric chart.

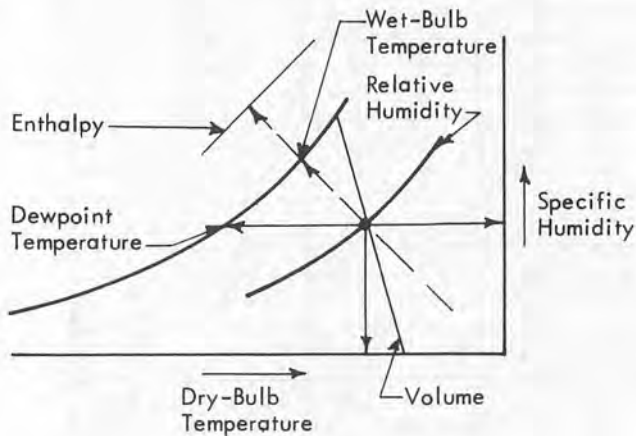


Fig 212-3. Properties of moist air on a psychrometric chart.

Example 212-1. Fig 212-4 illustrates the properties of air at 73°F db and 20% RH: wet-bulb temperature, 52°F; specific humidity, 0.0035 lb water vapor/lb da; enthalpy, 21.3 Btu/lb da; volume, 13.5 ft³/lb da; and dewpoint temperature, 30°F.

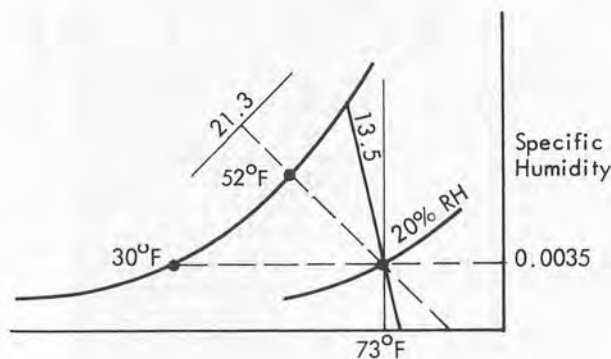


Fig 212-4. Properties of moist air at 73°F db and 20% RH.

Air-Water Vapor Mixture Processes

Air conditioning processes include heating, cooling, humidifying, or dehumidifying air-water vapor mixtures. A number of processes in agricultural engineering involve conditioning air-water vapor mixtures. Livestock housing usually includes some degree of environmental modification.

Crop drying is adiabatic wetting of the drying air. Design of any fogging process, whether of water, insecticide, herbicide, or others, requires knowledge of air conditioning processes. Also of interest in agricultural engineering is the plant, soil, and air dynamics relationship involving evapotranspiration.

Sensible Heating is adding heat to air without changing its specific humidity. Applications of sensible heating include heated-air grain drying and winter heating of room air in livestock and poultry buildings.

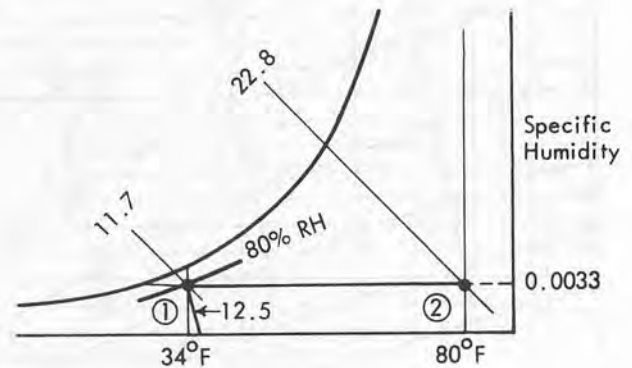


Fig 212-5. Sensible heating.

Example 212-2. Determine the heat required to raise 1250 ft³ of air at condition (1), 34°F db and 80% RH to (2), 80°F db. What is the final relative humidity?

Sensible heating is shown in Fig 212-5 as a horizontal line from 34°F db and 80% RH, to 80°F db. The relative humidity at state 2 is about 15%. At condition (1) the volume is about 12.5 ft³/lb da; enthalpy is about 11.7 Btu/lb da; the dewpoint temperature is 28°F; and specific humidity is 0.0033 lb water/lb da. The enthalpy at (2) is about 22.8 Btu/lb. The heat added can be determined by either of the two following methods.

If ventilation is in cfm heat needed is in Btu/minute.

$$q = M_a [c_p (t_2 - t_1) + 0.45 W (t_2 - t_1)]$$

$$M_a = 1250 \text{ ft}^3 \text{ of air} / V$$

$$\begin{aligned} q &= (1250/12.5) [0.24(80 - 34) \\ &\quad + 0.45 \times 0.0033 (80 - 34)] \\ &= 1,110 \text{ Btu} \end{aligned}$$

or

$$\begin{aligned} q &= M_a (h_2 - h_1) \\ &= (1250/12.5) (22.8 - 11.7) \\ &= 1,110 \text{ Btu} \end{aligned}$$

Sensible Cooling is cooling at constant specific humidity. An example is air passing over a cooling coil having a surface temperature above the dewpoint temperature of the air. Sensible cooling is represented, as in Fig 212-6 as a horizontal line from right to left. The final temperature cannot be below the initial dewpoint temperature, or water vapor condenses and the process removes latent heat.

Example 212-3. Determine the amount of heat removed from 1400 ft³ of air initially at 90°F db and 64°F wb, which is cooled to 60°F without changing the moisture content (sensible cooling).

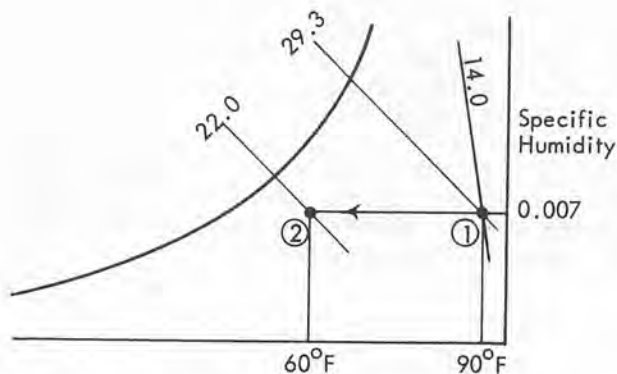


Fig 212-6. Sensible cooling process.

The properties of the mixture from the psychrometric chart are shown in Fig 212-6. Volume (1) is 14.0 ft³/lb da, and enthalpy is 29.3 Btu/lb da. The enthalpy at (2) is 22.0 Btu/lb da. The specific humidity remains constant at 0.007 lb of water vapor/lb da. The sensible heat, q , removed is:

$$\begin{aligned} 1q_2 &= M_a (h_1 - h_2) \\ &= (1400/14) (29.3 - 22.0) \\ &= 730 \text{ Btu} \end{aligned}$$

The heat removed can also be calculated by:

$$\begin{aligned} 1q_2 &= M_a [c_p (t_1 - t_2) + 0.45 W (t_1 - t_2)] \\ &= (1400/14) [0.24 (90 - 60) \\ &\quad + 0.45 \times 0.007 (90 - 60)] \\ &= 729.5 \text{ Btu} \end{aligned}$$

Evaporative Cooling is an adiabatic saturation process (no heat gained or lost), and follows upward along a constant wet-bulb temperature line. Air to be cooled is brought in contact with water at a temperature equal to the wet-bulb temperature of the air. The sensible heat of the initial air evaporates the water, lowering the air's dry-bulb temperature. Sensible heat is converted to latent heat in the added vapor, so the process is adiabatic. Evaporative cooling is most effective in hot dry climates where wet-bulb depression is large, and where the disadvantage of increased humidity is more than offset by a relatively large temperature drop.

Example 212-4. Air at 86°F db and 20% RH is saturated by spraying recirculated water into it. What is the dry-bulb temperature of the saturated air, and how much moisture is added per pound of dry air in the evaporative cooling process?

In Fig 212-7, the wet-bulb temperature at (1) is 60°F. Since the process is adiabatic and nearly along a line of constant wet-bulb, the dry-bulb temperature at saturation will also be 60°F.

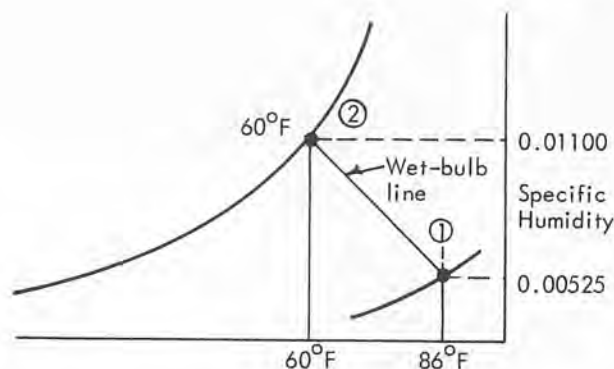


Fig 212-7. Evaporative cooling process.

The difference in specific humidity, $W_2 - W_1$, between the two points is $0.01100 - 0.00525 = 0.00575$ lb/lb da, the quantity of water vapor added to the air.

Heating and Humidifying of ventilation air occurs as it moves through livestock buildings. Animals and poultry produce heat, vapor, and water; both sensible heat and water vapor are added to ventilating air, as shown in Fig 212-8.

The process is indicated by the dashed curved line between the initial (1) and final (2) conditions.

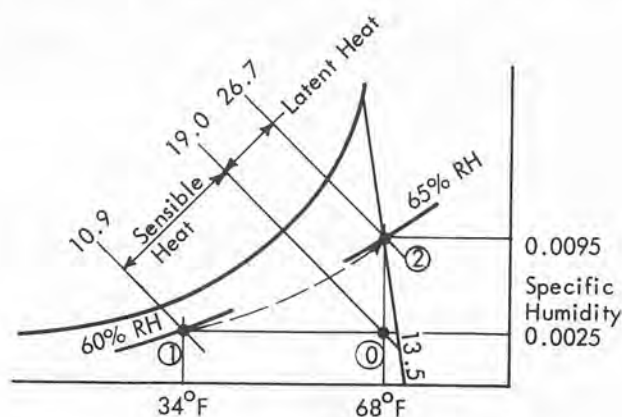


Fig 212-8. Heating and humidifying process.

Example 212-5. Moist air enters a farrowing house at 34°F db and 60% RH, replacing air removed from the space by an exhaust fan. If air leaves at 2700 cfm, 68°F db, and 65% RH, how much latent heat and sensible heat are added per hour to the air inside the building?

From Fig 212-8, the air volume removed by the exhaust fan at state (2) is 13.5 ft³/lb da. To separate the total enthalpy (energy) change into sensible and latent portions, locate state (0), which divides the process into a sensible heating process from state (1) to (0) and a humidifying process

from state (0) to (2). State (0) has the same specific humidity as state (1) and the same dry-bulb temperature as state (2). Thus $h_1 = 10.9$ Btu/lb da, $W_1 = 0.0025$ lb of water/lb da, $h_0 = 19.0$ Btu/lb da, and $h_2 = 26.7$ Btu/lb da. The rate at which air flows through the building is:

$$M_a = \frac{\text{cfm} \times 60 \text{ min/hr}}{V \text{ ft}^3/\text{lb da}}$$

$$M_a = \frac{(2700)(60)}{13.5} = 12,000 \text{ lb da/hr}$$

Sensible heat added to the air is:

$$\begin{aligned} 1q_0 &= M_a (h_0 - h_1) \\ &= 12,000 (19.0 - 10.9) = 97,200 \text{ Btu/hr.} \end{aligned}$$

Latent heat added to the air is:

$$\begin{aligned} 0q_2 &= M_a (h_2 - h_0) \\ &= 12,000 (26.7 - 19.0) = 92,400 \text{ Btu/hr.} \end{aligned}$$

Total heat added is:

$$1q_2 = 189,600 \text{ Btu/hr}$$

Cooling and Dehumidifying implies lowering both dry-bulb temperature and specific humidity. The process path depends on the type of equipment used. In summer air conditioning, air passes over a cold finned-type evaporator coil of a refrigeration unit. The air is cooled below the dewpoint temperature; moisture condenses. Unless reheated or initially saturated, the final relative humidity of the moist air is always higher than at the start. Both sensible heat and latent heat are removed from the air in this process.

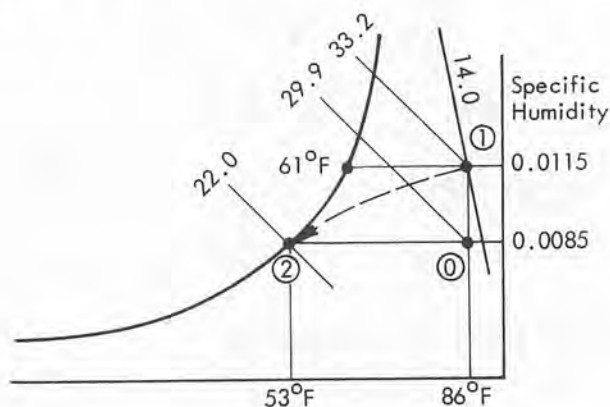


Fig 212-9. Cooling and dehumidifying process.

Example 212-6. How many tons of refrigeration are required to cool 700 cfm of air at (1) 86°F dry-bulb and 61°F dewpoint to (2) 53°F dry-bulb and 100% RH? How much moisture is removed? What is the ratio of latent heat to sensible heat removed in this process? (A ton of refrigeration is equal to a cooling capacity of 200 Btu/min. or 12,000 Btu/hr.)

Required properties from the psychrometric chart for the problem are shown in Fig 212-9.

At state (1) enthalpy is 33.2 Btu/lb da, volume is 14.0 ft³/lb da, and specific humidity is 0.0115 lb of water vapor/lb da.

Enthalpy at (2) is 22.0 Btu/lb da and specific humidity is 0.0085 lb of water vapor/lb da. State (0) divides the process into dehumidifying and sensible cooling segments; enthalpy is 29.9 Btu/lb da. The refrigeration required is:

$$\begin{aligned} q_T &= M_a (h_1 - h_2) \\ &= (700/14.0) (33.2 - 22.0) \\ &= 560 \text{ Btu/min or 2.8 tons of refrigeration} \end{aligned}$$

The water removed is:

$$\begin{aligned} M_w &= (700/14.0) (0.0115 - 0.0085) \\ &= 0.15 \text{ lb/min} \end{aligned}$$

The ratio of latent heat to sensible heat removed is:

$$\frac{q_l}{q_s} = \frac{h_1 - h_0}{h_0 - h_2} = \frac{33.2 - 29.9}{29.9 - 22.0} = 0.42$$

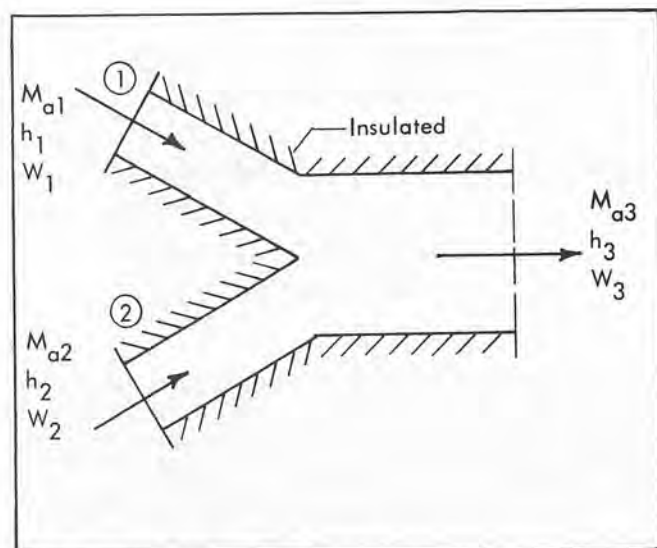


Fig 212-10. Adiabatic mixing of moist air.

Adiabatic Mixing of Moist Air. A common process in air-conditioning is mixing moist air at two conditions to obtain air at a third. If the mixing is adiabatic as in Fig 212-10, it is governed by the following balances:

$$\text{lb-air balance: } M_{a1} + M_{a2} = M_{a3} \quad \text{Eq 212-10a}$$

$$\text{heat balance: } M_{a1}h_1 + M_{a2}h_2 = M_{a3}h_3 \quad \text{Eq 212-10b}$$

$$\text{lb-water balance: } M_{a1}W_1 + M_{a2}W_2 = M_{a3}W_3 \quad \text{Eq 212-10c}$$

$$\begin{aligned} \text{Substitute for } M_{a3} \text{ from Eq 10a:} & \\ &= (M_{a1} + M_{a2})W_3 \\ &= M_{a1}W_3 + M_{a2}W_3 \end{aligned}$$

Eq 212-11

$$\text{Transpose: } M_{a2}(w_2 - w_3) = M_{a1}(w_3 - w_1)$$

$$\text{Similarly: } M_{a2}(h_2 - h_3) = M_{a1}(h_3 - h_1)$$

$$\text{and, by division: } \frac{h_2 - h_3}{h_3 - h_1} = \frac{w_2 - w_3}{w_3 - w_1} = \frac{M_{a1}}{M_{a2}}$$

The state point of the air-vapor mixture after adiabatic mixing of air at two different states falls on the straight line connecting the two initial states. From Eq 212-11, the final state is the point dividing the line into two parts proportional to the weights of dry air being mixed.

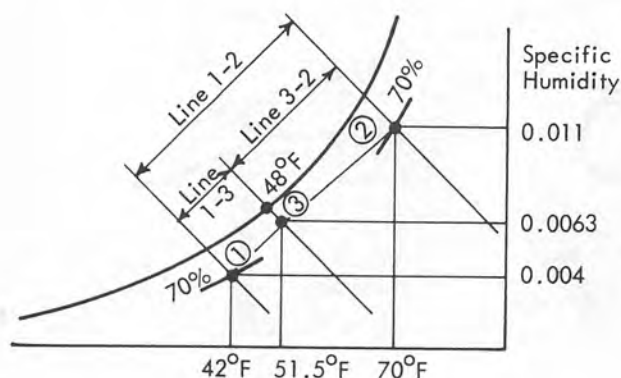


Fig 212-11. Adiabatic mixing process.

Example 212-7. 2540 cfm of outside air at 42°F db and 70% RH is adiabatically mixed with 1360 cfm of air at 70°F db and 70% RH. Find the dry-bulb and wet-bulb temperatures of the resulting mixtures. See Fig 212-11. Locate states (1) and (2) on the psychrometric chart; $V_1 = 12.7 \text{ ft}^3/\text{lb da}$; $V_2 = 13.6 \text{ ft}^3/\text{lb da}$. Therefore:

$$M_{a1} = \frac{2540}{12.7} = 200 \text{ lb da/min}$$

$$M_{a2} = \frac{1360}{13.6} = 100 \text{ lb da/min}$$

According to Eq 212-11:

$$\frac{\text{Line 3-2}}{\text{Line 1-3}} = \frac{M_{a1}}{M_{a2}} = \frac{200}{100} = 2.0$$

The line segment 1-3 is 1/2 line 3-2, or 1/3 the entire line 1-2. Locate state (3) with a ruler, and read the temperatures of 51.5°F db and 48°F wb.

CHAPTER 213 TEMPERATURE AND MOISTURE BALANCE

Ventilation is a process for controlling some environmental factors. As air moves through a building its temperature may rise or fall, and the amount of water it carries (specific humidity, W) may increase or decrease.

During the winter, a livestock shelter tends to be cold and damp; during the summer it tends to be hot and humid. With controlled ventilation designed to maintain desirable heat and moisture balances a near-optimum environment can be maintained.

A temperature balance relates sensible heat sources, heat losses, temperatures, and ventilation rate. A moisture balance relates latent heat sources and losses and ventilation rate. Fig 213-1 illustrates an overall moisture balance between outside air, conditions in the building, and exhausted ventilation air.

In the following discussion most comments refer to winter conditions in a livestock building. Fig 213-2 gives one set of winter design temperatures—those daily means (average of 24 hourly readings)

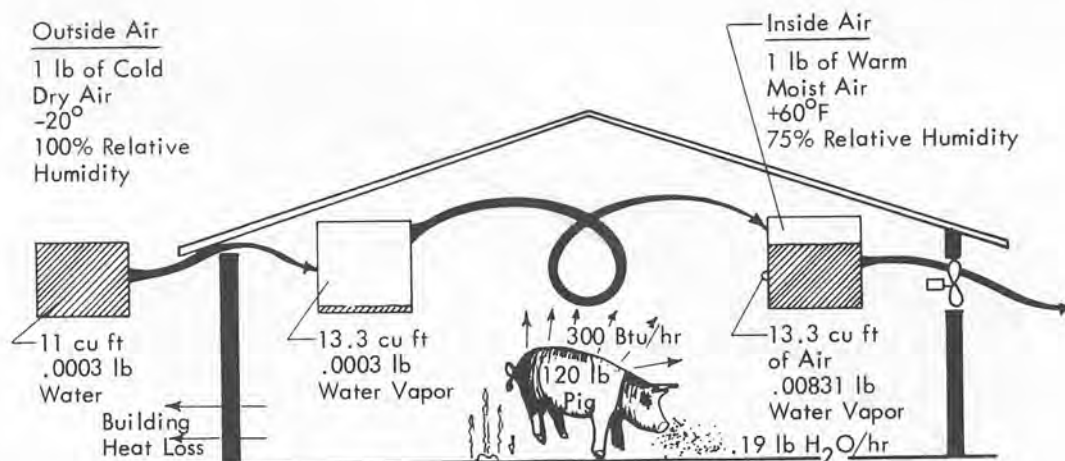
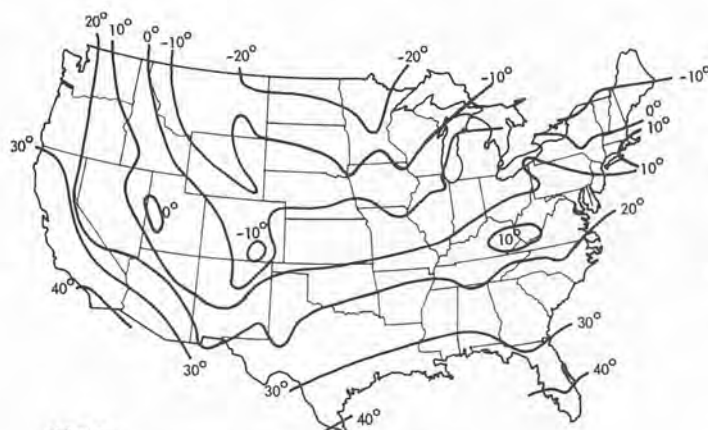
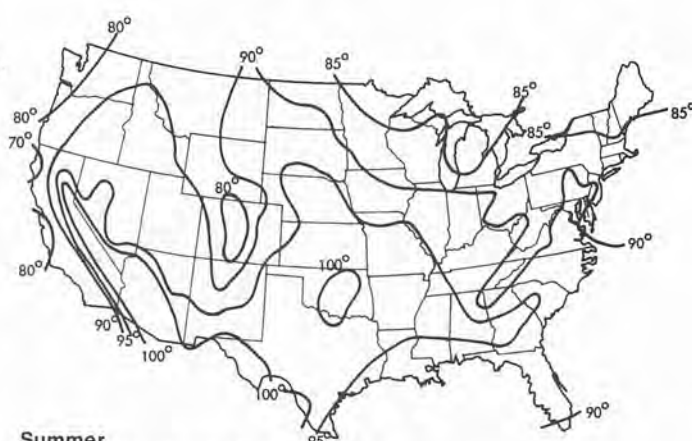


Fig 213-1. Winter ventilation in a controlled environment.



Winter

Very rough Isotherms for average year
Lower temperatures 2½% (54 hrs)
of the time Dec thru Feb
ASHRAE Data



Summer

Very rough Isotherms for average year
Temperatures exceeded 2½% (150 hrs)
of the time June thru Sept
ASHRAE Data

Figure 213-2. Design temperatures.

occurring about once every 13 years. Other typical design temperatures include mean January temperature, and the temperature below 95% or 99% of all winter temperatures.

Sensible Heat Balance

The design procedure for ventilation assumes an inside condition within the comfort zone of the animals to be housed, (or the optimum temperature itself), an outdoor condition within the anticipated weather range, Fig 213-2, and heat and moisture production and losses within the ventilated space.

Heat sources include, Btu/hr:

$$\begin{aligned} q_{an} &= q_s + q_l && \text{animal heat} = \text{sensible} \\ &&& + \text{latent heats} \\ q_m &= && \text{mechanical heat from lights,} \\ &&& \text{motors, etc} \\ q_{sr} &= && \text{supplemental heat from} \\ &&& \text{furnaces or lamps} \end{aligned}$$

Heat losses include, Btu/hr:

$$\begin{aligned} q_b &= \text{building heat loss through doors, walls,} \\ &\quad \text{etc.} \\ q_v &= \text{sensible heat lost in ventilating air} \\ q_e &= \text{sensible heat used to evaporate water} \\ &\quad \text{and converted to latent heat} \end{aligned}$$

Sensible heat raises temperatures. If building temperature is to remain constant, sensible heat produced in the building must all be removed. If too much is removed, temperatures will drop; if not enough is removed, temperatures will rise.

A sensible heat balance in Btu/hr is:

$$q_s + q_m + q_{sr} = q_b + q_v + q_e \quad \text{Eq 213-1}$$

Usually, either the supplemental heat, q_{sr} , or the ventilating heat, q_v , are the unknowns. For a given

building and animal population, the ventilation rate may be assumed and the needed furnace size determined. Or, ventilation rate may be determined if either known supplemental heat (such as brooder lamps) or no supplemental heat is assumed. Note that only the sensible heat portion of animal heat is used.

Calculating sensible heat gains

- Animal sensible heat gain is the sensible heat production of each animal at the assumed indoor temperature, times the number of animals.
- Mechanical heat gain may be estimated from:
3.4 Btu/hr-watt incandescent lighting
4.1 Btu/hr-watt fluorescent lighting
4000 Btu/hr-horsepower, fractional hp motors
- Supplemental heat is usually computed from the sensible heat balance. Enough heat is supplied with a furnace, floor heat, or brooder heat to make up for excessive heat losses.

Calculating sensible heat losses

- Building heat loss is the sensible heat lost through walls, ceilings, floor, windows, and doors. It is calculated as discussed in Chapter 214, and is dependent on the type of construction, amount and type of insulation, the areas of the surfaces, and the indoor-outdoor temperature difference.
- Sensible heat lost in ventilating air is the amount of heat to raise the temperature of incoming air to the exhaust temperature:

$$q_v = M_a c_p \Delta t \quad \text{Eq 213-2}$$

or,

$$q_v = M_a (h_0 - h_1) \quad \text{Btu/hr}$$

where:

- M_a = amount of ventilating air, lb/hr
- h_0 = enthalpy of exhaust air at the leaving temperature but at the entering specific humidity. See Fig 212-8.
- h_1 = enthalpy of incoming air

- q_e is the heat needed to change water at room temperature to water vapor at room temperature.

$$q_e = M_w \times 1036 \quad \text{Btu/hr} \quad \text{Eq 213-3}$$

where:

- M_w = amount of water being evaporated (lbs/hr)
- 1036 = approximate heat of vaporization (Btu/lb water evaporated)

Moisture Balance

As ventilation air moves through a building it tends to evaporate moisture from floors, pits, and other wet surfaces. As animals breathe, moisture is evaporated from their lungs. To maintain desirable indoor conditions, enough moisture is removed from the building to keep the relative humidity below about 80%.

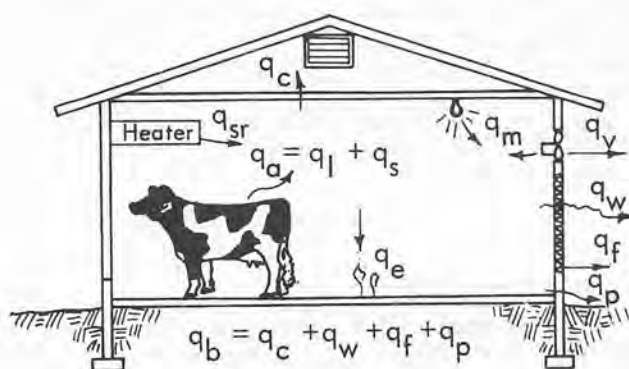


Fig 213-3. Winter conditions—heat gains and losses.

Moisture sources

• Water vapor production of the animals; it is calculated from latent heat production.

• Evaporation of moisture from various wet surfaces in the building. Moisture losses are ventilation air and, perhaps, free water drained away. Usually only free water to be removed by ventilation is included in "sources" so that correction for water removed by other means may be neglected in "losses".

Calculating moisture balance

Overall moisture balance is:

$$M_a W_2 = M_a W_1 + W_a + W_e \quad \text{Eq 213-4}$$

or,

$$M_a (W_2 - W_1) = W_a + W_e$$

where:

$$\begin{aligned} M_a &= \text{lb da/hr} \\ W_2^a &= \text{vapor in exhaust air, lb/lb da} \\ W_1^a &= \text{vapor in incoming air, lb/lb da} \\ W_a^a &= \text{vapor from animals, lb/hr} \\ W_e^a &= \text{vapor from surface water evaporation, lb/hr} \end{aligned}$$

• Latent heat, q_l , from the animals is tabulated in Table 214-7, and the hourly rate of moisture production is calculated:

$$W_a = q_l / 1036 = \text{lb/hr}$$

• Moisture to be removed by evaporation, W_e lb/hr, is estimated.

• Moisture removed by ventilating air is the gain in specific humidity of the air as it moves through the building = $M_a(W_2 - W_1)$.

Ventilation Rates

Recommended ventilation rates for various conditions can be tabulated, with the values based on specified assumptions. Or, a ventilation rate for any condition can be easily calculated. Eq 213-1, the sensible heat balance equation, is solved for q_s , the sensible heat removed by ventilation air.

Then the ventilation rate for sensible heat balance is computed:

$$Q = \frac{V \times q_v}{(0.24)(60)(t_2 - t_1)} \quad \text{Eq 213-5}$$

where:

$$\begin{aligned} Q &= \text{ventilation rate, cu ft air/minute} \\ &= \text{cfm.} \\ V &= \text{specific volume of air, cu ft/lb da.} \\ &\text{Use } V \text{ at inside conditions for exhaust systems, and } V \text{ at outside conditions for pressure systems.} \\ q_v &= \text{heat loss in ventilation air, Btu/hr.} \\ &= q_s + q_m + q_{sr} - q_b - q_e, \text{ from Eq 213-1.} \end{aligned}$$

$$t_2 - t_1 = (\text{indoor} - \text{outdoor}) \text{ temperature difference, } ^\circ\text{F.}$$

The units of Eq 213-5 are:

$$\begin{aligned} \frac{\text{cu ft}}{\text{min}} &= \frac{\frac{\text{cu ft}}{\text{lb da}} \times \frac{\text{Btu}}{\text{hr}}}{\frac{\text{Btu}}{\text{lb da-}^\circ\text{F}} \times \frac{\text{min}}{\text{hr}} \times ^\circ\text{F}} \\ &= \frac{\text{cu ft}}{\text{lb da}} \times \frac{\text{Btu}}{\text{hr}} \times \frac{\text{lb da-}^\circ\text{F}}{\text{Btu}} \times \frac{\text{hr}}{\text{min}} \times \frac{1}{^\circ\text{F}} \\ &= \text{cfm} \end{aligned}$$

The ventilation rate to maintain a moisture balance is:

$$Q = \frac{V}{60} \times \frac{W}{W_2 - W_1} \quad \text{Eq 213-6}$$

where:

$$\begin{aligned} Q &= \text{the ventilation rate, cu ft/min} \\ V &= \text{specific volume, as in Eq 213-5} \\ W &= \text{moisture to be removed, lb/hr} \\ &= \frac{\text{latent heat of production of animals}}{1036 \text{ heat of vaporization}} \\ &\quad + \text{evaporated water} \\ W_2 - W_1 &= \text{indoor - outdoor specific humidity difference, lb/lb da} \end{aligned}$$

The units of Eq 213-6 are:

$$\begin{aligned} \frac{\text{cu ft}}{\text{min}} &= \frac{\frac{\text{cu ft}}{\text{lb da}} \left[\frac{\text{Btu}}{\text{hr}} \div \frac{\text{Btu}}{\text{lb}} + \frac{\text{lb}}{\text{hr}} \right]}{\frac{\text{min}}{\text{hr}} \left[\frac{\text{lb}}{\text{lb da}} - \frac{\text{lb}}{\text{lb da}} \right]} \\ &= \frac{\text{cu ft}}{\text{lb da}} \times \frac{\text{Btu}}{\text{hr}} \times \frac{\text{lb}}{\text{Btu}} \times \frac{\text{lb da}}{\text{lb da}} \times \frac{\text{hr}}{\text{min}} \\ &\quad \times \frac{\text{lb da}}{\text{lb}} \end{aligned}$$

Compare the ventilation rates for moisture control and for temperature control. If more air is needed for moisture control than for temperature balance, the increased air flow will increase sensible heat losses and supplemental heat is needed to prevent indoor temperatures dropping below the desired level. If the ventilation rate for heat balance is the higher, room moisture levels will be less than assumed, which is usually acceptable.

Ventilation Curves

The two ventilation rate equations, Eq 213-5 for heat and Eq 213-6 for moisture, can be used to plot a graph of ventilation rate versus outside temperature for a particular building and animal combination. See Fig 213-4.

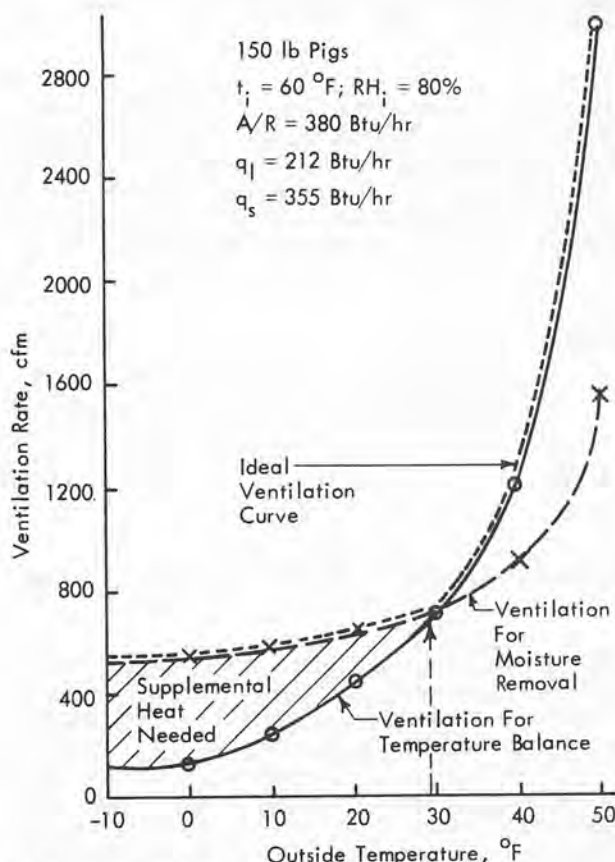


Fig 213-4. Ventilation curves.

Example

What ventilation rate is needed in a swine finishing confinement building with a totally slotted floor, and 100 head of 150-pound pigs for outside temperatures from -10 to 50°F? Assume inside conditions 60°F and 80% RH. Also, assume outside RH = 80%. Use 212 Btu/hr latent and 355 Btu/hr sensible heat production for 150-lb pigs on slotted floors.

Moisture = (212 Btu/hr latent heat) / (1036) = 0.20 lb water / hr-hog

Total moisture = 0.20 x 100 = 20 lb water/hr
The value, 212 Btu/hr, is for slotted floors so no additional allowance is needed for water being evaporated.

At 50°F, 80% RH outside, $W_1 = 0.00611$ lb water / lb air.

at 60°F, 80% RH inside, $W_2 = 0.0089$ lb water / lb air.

at 60°F, 80% RH inside, $V = 13.3$ cu ft / lb da.

$$Q = \frac{V}{60} \times \frac{W}{W_2 - W_1}$$

$$= \frac{13.3}{60} \times \frac{20}{(0.0089 - 0.00611)}$$

$$= 1590 \text{ cfm at } 50^\circ\text{F outside}$$

Heat = (355 Btu/hr sensible heat) x (100 head) = 35,500 Btu/hr; add no extra heat for evaporation of water.

Assume $A/R = 380$ Btu/hr-°F for this building at 50°F outside:

$$Q = \frac{V}{14.4 (\Delta t)} [q_s - \frac{A}{R} (\Delta t)]$$

$$= \frac{13.3}{14.4 (60 - 50)} [35,500 - 380(60 - 50)]$$

$$= 2928 \text{ cfm at } 50^\circ\text{F outside}$$

Similar procedures for other outside temperatures yield points on the curves as follows:

Temp	for heat	for moisture
50°F	2928 cfm	1590 cfm
40°F	1288 "	935 "
30°F	739 "	721 "
20°F	469 "	617 "
10°F	304 "	565 "
0°F	103 "	536 "
-10°F	117 "	515 "

The actual ventilation rate must meet the maximum demand, and so should follow the moisture removal curve to about 30° and the heat removal curve for higher temperatures. At outside temperatures below the point of intersection of the two curves, supply supplemental heat to maintain 60°F inside. At outside temperatures above the intersection, the inside relative humidity will be below the design RH = 80%.

When it is -10°F outside, 515 cfm of outside ventilation air are heated from -10°F to 60°F. The hog sensible heat warms 117 of the 515 cfm ventilation rate to 60°F; supplemental heat warms the other 400 cfm.

The amount of supplemental heat needed is calculated from:

$$q = M_a c_p \Delta t \quad \text{Eq 213-7}$$

where:

q = needed Btu's.

$M_a = Q/V$.

Q^a = cfm of air heated.

V = specific volume of ventilation air; use V for pressure systems and V_1 for exhaust systems.

c_p = specific heat of air, about 0.24 Btu/lb-°F.

Δt = difference between outside temperature and temperature to which ventilation air is heated, °F.

$$q = M_a c_p \Delta t = \frac{Q}{V} c_p \Delta t$$

$$= \frac{400 \text{ ft}^3}{\text{min}} \times \frac{1 \text{ lb}}{11.33 \text{ ft}^3} \times \frac{0.24 \text{ Btu}}{1 \text{ lb}^\circ\text{F}}$$

$$\times \frac{(60 - (-10))^\circ\text{F}}{1}$$

$$= 593 \text{ Btu/min or about } 35,600 \text{ Btu/hour}$$

Supplemental heat can also be determined using Eq 213-2.

Another design example is at the end of Chapter 214.

CHAPTER 214 INSULATION AND VAPOR BARRIERS*

Effective livestock buildings have a variety of features designed to provide an optimum environment of temperature, moisture, air movement and gas content; features like tight construction, insulation, vapor barriers, insulated doors and windows, and ventilation systems.

An enclosed building should be reasonably tight. Loose construction and unplanned openings make it difficult to control the amount and movement of ventilation air.

Insulation

Insulation is any material that reduces the rate at which heat is transferred from one area to another. Although all building materials have some insulation value, the term "insulation" is generally reserved for a family of products designed to provide this one service.

Insulation has several functions. **First**, it helps conserve heat during periods of cold weather. Conserving animal or bird heat helps maintain desirable housing conditions without the addition of unrealistic amounts of supplemental heat. Fig 214-1.

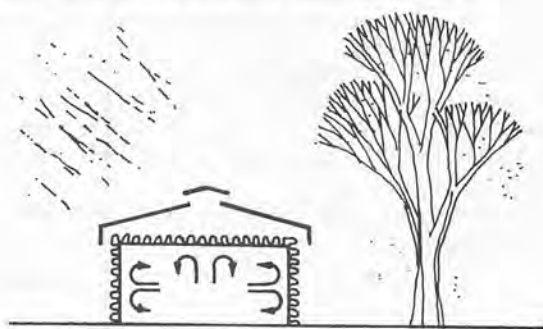


Fig 214-1. Insulation reduces the rate of heat loss from buildings during cold weather.

Second, insulation helps reduce the rate of heat gain in hot weather. Fig 214-2. The temperature of building walls and roofs exposed to direct sunlight is as much as 50°F above air temperature.

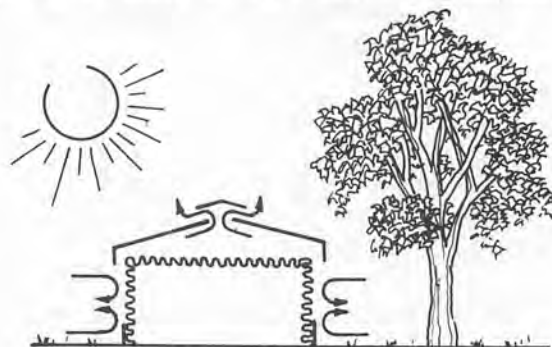


Fig 214-2. Insulation reduces the rate at which heat passes into a building during hot weather.

One result of reducing heat loss and heat gain is a desirable reduction in the daily changes in indoor temperatures. An insulated building is cooler in the warm part of the afternoon and warmer in the cold early morning hours. The total temperature variation during the day is reduced. Fig 214-3.

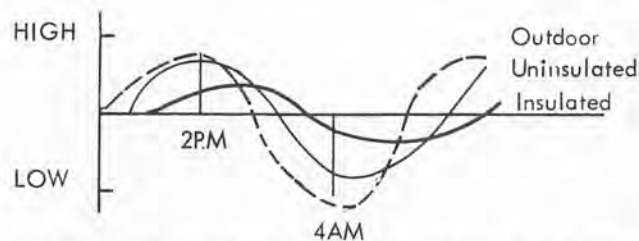


Fig 214-3. Insulation reduces temperature extremes in a building.

Third, surface condensation—"sweating"—can be controlled. In a poorly insulated building, the inside ceiling and wall surfaces become cold in the winter, bringing discomfort to animals nearby. When the surface temperature is low enough, the air next to the surface becomes saturated and moisture condenses. Fig 214-4. If the surface temperature is below freezing, frost forms. Well-insulated buildings reduce condensation and frost by keeping the walls and ceiling relatively warm.

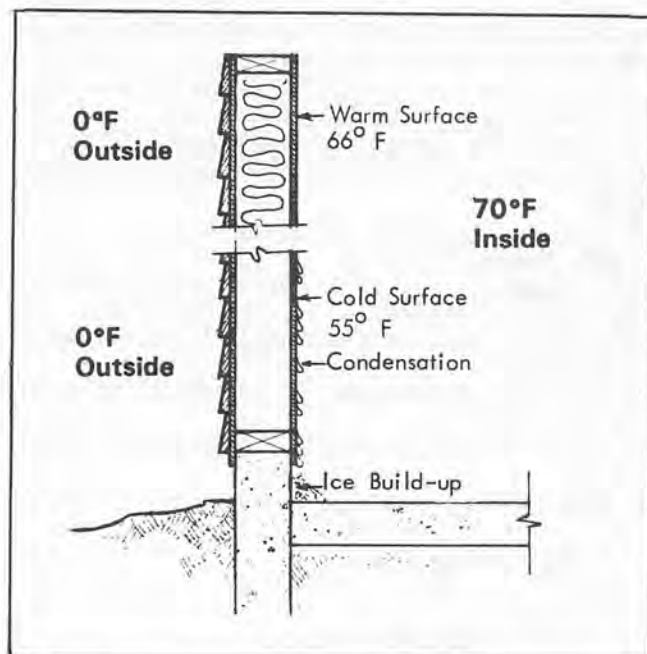


Fig 214-4. When warm, moist air comes into contact with a cold surface, condensation occurs. Insulation helps to control sweating by making the wall and ceiling surfaces warmer.

*Major credit for this publication goes to O.E. Cross and E.A. Olson, Agricultural Engineers at the University of Nebraska.

Fourth, correct foundation insulation reduces frost heaving, keeps floors warmer, and reduces heat losses. Insulate the outside of the foundation wall if possible, Fig 214-5: the wall above the floor is warmer, reducing condensation; the foundation below grade is warmer, reducing the hazard of frost heaving; the outer edge of the floor is warmer, increasing animal comfort; and total heat losses from the building are reduced. Traditional methods of placing insulation inside the foundation wall and under the floor reduce heat loss only through the floor.

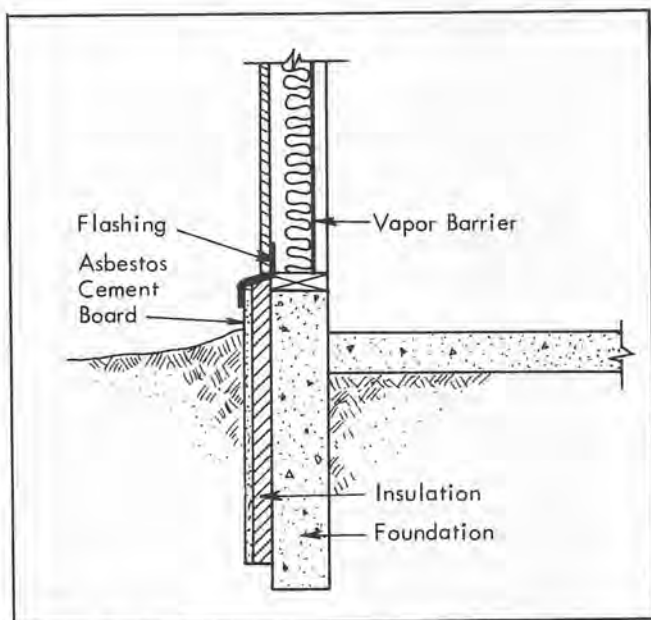


Fig 214-5. Placing perimeter insulation.

Types of insulation

The most common insulation is bulky, porous, lightweight material with countless air spaces. The lighter the material is, the better are its insulating qualities. Generally, the more air pockets in the material, the better it insulates. Some building materials, like wood, are good insulators, while others, like concrete and metal, are poor insulators.

Manufactured insulation is in several common forms. Answering the following questions helps determine the form to be selected for a particular job:

- How is it to be used? Is it to be purely for insulation, or does it also need to have some structural qualities?
- How adaptable is it to the particular use?
- What is its relative cost?
- Can it be installed easily?

Loose-fill insulation is packaged in bags. Almost all the common insulations—mineral wool, vermiculite, granulated cork, and others—come in this form. Loose-fill insulation is especially adapted for use in ceilings of existing buildings. Special precautions must be taken, however, when it is used in side walls. Settling does occur and some

parts of the wall may not be adequately insulated. A vapor barrier must be provided on the warm, or room, side of the wall and ceiling.

Insulation batts and blankets are among the easiest and cheapest ways to add insulation to a farm building. They come in thicknesses of 1"-6" and in widths to fit either 16" or 24" stud spacings. Many of these have a vapor barrier attached to one side (see Vapor Barriers).

Insulation board has some rigidity as well as insulation value. For use in livestock buildings, it must be treated to resist moisture. Some insulation boards have a vapor barrier on one side. Protect insulation board from physical damage by animals and equipment. Follow the manufacturer's recommendations for installing insulation board on spaced supports in a ceiling, roof, or wall.

Block or rigid insulation is usually used for perimeter or floor insulation, and should withstand moisture. The most common materials are expanded polystyrene, foam glass, polyurethane or asphalt-impregnated rigid insulation. Place perimeter insulation to protect the edges of a concrete floor. Fig 214-5.

Air space, as insulation, should not be less than $\frac{3}{4}$ " wide, because its effectiveness decreases rapidly as its width decreases. On the other hand, it should not be over about 4" wide, or convection currents will reduce its insulating value.

Reflective insulation is made from metallic foil such as aluminum foil, placed so that there are air spaces around it. It reflects almost all of the radiant heat that strikes it. Since only part of the heat to be retarded is radiant heat, reflective insulations need to have several air spaces to resist the flow of heat by conduction and convection.

Reflective insulation is highly efficient in resisting the flow of heat downward. For this reason it is effective in keeping out summer heat and allows the interior of the building to cool rapidly at night. Foil insulation is not commonly used as winter insulation in farm buildings.

Additives to concrete have been suggested for increasing insulation quality while retaining the strength of ordinary concrete. Some materials (for example, expanded shale, ground corncobs, or wood shavings) when substituted for some of the concrete aggregates increase the insulation value of that concrete, BUT at a considerable reduction in its strength. At present, no additive has been proved without bias to insulate concrete without a reduction in strength.

Selecting Insulation

Fig 214-6 shows how thick building materials must be to have the same insulation value as a 1" glass wool batt. For example, it takes 2.96" of plywood or 46.3" of concrete to equal the insulation value of 1" of glass wool.

Insulation, as well as other building materials, can be rated according to its ability to resist the flow of heat. This is commonly referred to as the "R" value. The R, or insulation value, may be

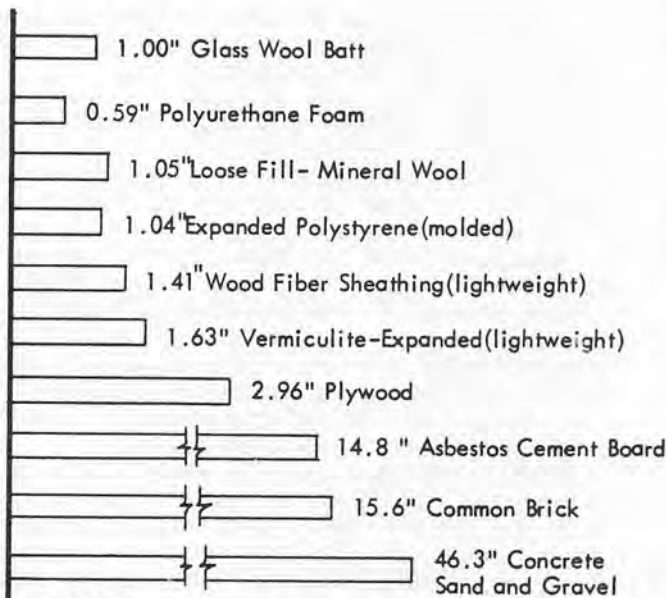


Fig 214-6. Material thickness required for equal insulation value.

given per inch of thickness, or for the total thickness of a material. The relative insulation values of some common building materials are shown in Table 214-1.

Other ways of expressing the value of insulation are the "k", "C", or "U" values. k is the heat (in British thermal units) per hour that passes through a piece of material 1' thick and 1' square, when the temperature difference between the two sides is 1°F. C is like k, except it's given for a total thickness: k glass wool = .27; C 3" glass wool = 0.09. U (over-all coefficient of heat transmission) is the Btu's that pass through a complete wall, ceiling, or floor construction, 1' square, in one hour per degree of temperature difference between the air on the warm side and the air on the cold side. The U value is 1/R.

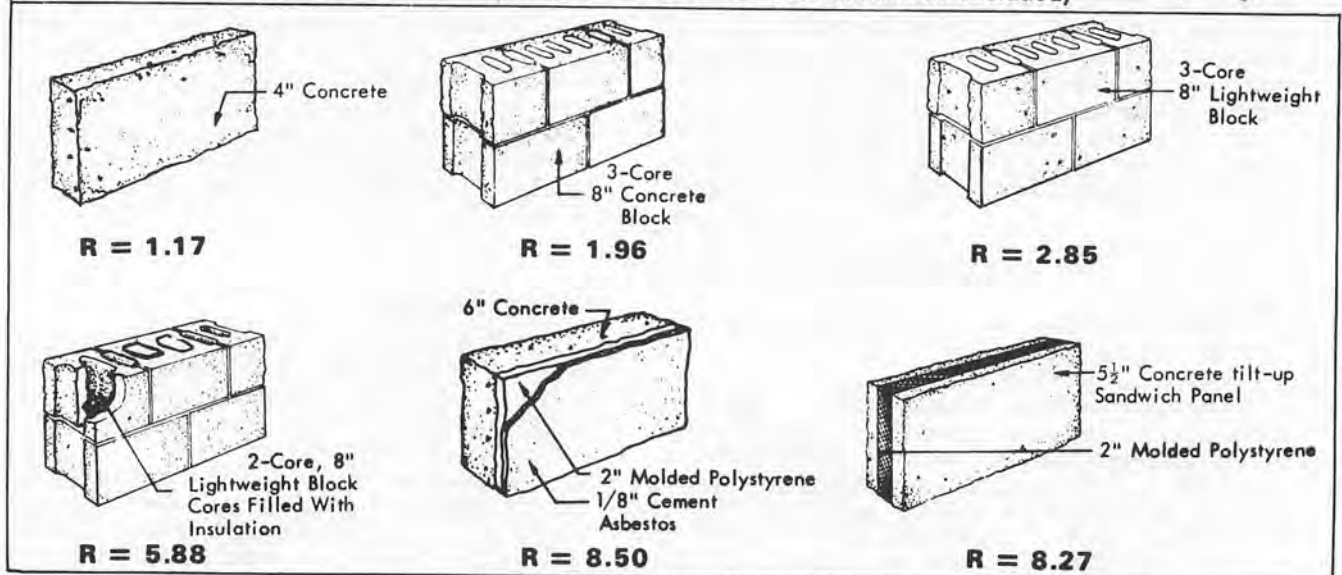
Table 214-1. Insulation R values for some common materials.¹ Values do not include surface conditions.

Material	Insulation value ²	
	Per inch thickness	For thickness listed
1. Batt or blanket insulation		
Glass wool, mineral wool or fiber glass	3.70	
2. Fill-type insulation		
Glass or mineral wool	3.00 to 3.50	
Vermiculite (expanded)	2.13 to 2.27	
Shavings or sawdust	2.22	
Paper or wood pulp	3.70	
3. Rigid insulation		
Wood fiber sheathing	2.27 to 2.63	
Expanded polystyrene, extruded	4.00 to 5.26	
Expanded polystyrene, molded	3.57	
Expanded polyurethane (aged)	6.25	
Glass fiber	4.00	
4. Ordinary building materials		
Concrete, poured	0.08	
Plywood, 3/8"	1.25	.47
1/2"	1.25	.63
Hardboard, 1/4"	1.00 to 1.37	
Cement asbestos board, 1/8"		.03
Lumber (fir, pine) 3/4"	1.25	.94
Wood beveled siding 1/2" x 8"		.81
Asphalt shingles		.44
Wood shingles		.94
5. Window glass, includes surface conditions		
Single-glazed		.89
Single-glazed + storm windows		1.79
Double-pane insulating glass	1.45 to 1.73	
6. Air space (3/4" or larger)		.90
7. Surface conditions		
Inside surface		.68
Outside surface (15 mph wind)		.17

¹From ASHRAE Handbook of Fundamentals, 1972.

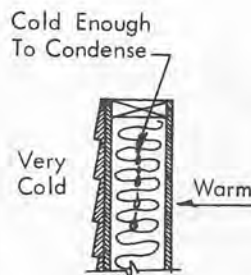
²Mean temperature of 76°F.

Table 214-2. Insulation R values for concrete wall construction. (Surface conditions included)



Protect insulation from moisture, Use vapor barriers

In livestock buildings and other buildings where the relative humidity is high, protect insulation from moisture. Moisture, in the form of water vapor, tends to move from warmer moist areas to the cooler outside. Moisture enters the wall, moves outward, and condenses when it reaches a cold enough area. Condensed water in the wall greatly reduces the value of the insulation and may damage the wall.



To eliminate this flow of moisture, place a supplemental vapor barrier near the warm side of the wall. Immediately beneath the interior lining material is best. Fig 214-8.

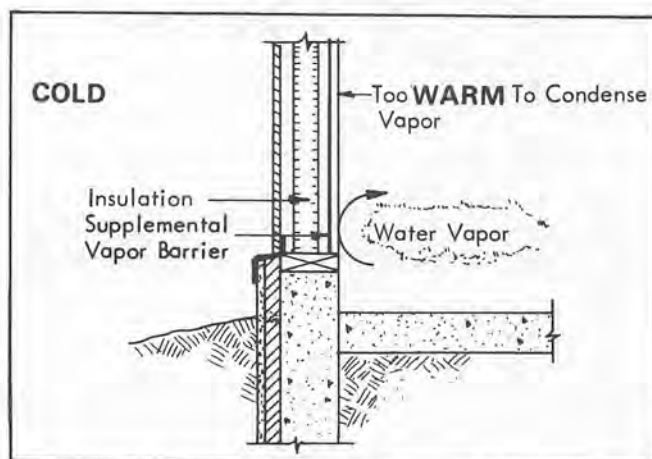


Fig 214-8. Vapor barriers prevent the movement of water vapor into wall and ceiling spaces and materials.

Common vapor barriers are aluminum foil, 4 mil plastic film, and some of the asphalt-impregnated building papers. Table 214-6 shows the water vapor transmission ratings of some common vapor barriers and building materials. The numbers represent the amount of vapor transmission, so the smaller numbers represent the better vapor barriers. A material rated below 1.0 is usually considered a good vapor barrier.

Consider the construction joints of the materials when comparing the water vapor transmission values. Vapor barrier materials are lapped to prevent moisture from entering through the joints. In concrete sandwich walls, if the concrete is mixed according to instructions, no vapor barrier is required.

Table 214-6. Water vapor transmission of common building materials¹, perms.

1 Perm = 1 Grain/hr-ft²-in.Hg

Vapor Barriers

Aluminum foil (1 mil)	0.0
4 mil polyethylene (plastic film)	.08
Kraft and asphalt building paper	.3
Two coats of aluminum paint (in varnish) on wood	.3-5

Common Building Materials

1" extruded expanded polystyrene	1.2
15 lb tar felt building paper	4.0
1/2" insulation board, uncoated	50 to 90
1/4" 3-ply exterior plywood	.7
4" brick masonry	.8
4" poured concrete wall	.8
4" glazed tile masonry	.12
8" concrete block	2.4

¹ From ASHRAE Handbook of Fundamentals, 1972.

Applying different types of insulation

Each type of insulation has its application problems. Follow the manufacturer's recommendations.

Batts or blankets must be protected from moisture. Moisture will destroy a batt's insulation value. The vapor barrier on many batts is not sufficient for livestock buildings. Use a separate vapor barrier between the batts and the inside wall or ceiling lining.

Because mechanical damage permits moisture to enter batt insulation, an inside wall and ceiling lining is almost always required. A batt with a vinyl backing can be applied to ceilings without a ceiling lining, but they usually sag in time. These batts are stapled directly to the ceiling joists or rafters.

If insulation board is used alone, it is difficult to get the builder to use the 3" required in the roofs of livestock buildings.

Most insulation boards used in farm buildings have been chemically treated to make them moisture resistant. Some boards have a plastic covering that gives them a good vapor barrier.

Many builders span too large a distance when applying insulation board. Follow the manufacturer's recommendations. When insulation board is used as a false ceiling, supports can be located up to 24" on center, depending on the thickness of the board.

Some rigid plastic foams are resistant to the absorption of moisture, but others—the low-density beadboards—offer little resistance. The vapor transmission ratings of the different types of foam range from 0.4 to 5.8 perms. Use a separate vapor barrier if the perm rating is above 1.0.

Some foam is applied by butting the square edges of the rigid boards together. A small amount

of shrinkage leaves small cracks (sometimes up to an eighth of an inch). Moisture can escape, condense on the cold roof and drip onto the foam. Tongue-and-groove edges help eliminate the problem. Taping the joints has not been satisfactory. Taping the joints on newer foams with a plastic film on one side has shown greater promise.

Use enough insulation. Learn the insulation value of the material and use enough to provide a satisfactory insulation value. Consider summer as well as winter conditions.

Don't be concerned about the insulation value of the lining. Apply the insulation required inside the wall. Choose a lining material for its durability, ease of cleaning, and appearance.

Provide a good vapor barrier. Insulation materials that possess a satisfactory perm rating will still require vapor-tight joints.

Protect insulation from rodents and birds. Also

protect against damage by animals, workers, and equipment. Few insulations applied with one side exposed have proved to be satisfactory in livestock buildings.

Insulate all areas. In metal-frame or masonry buildings columns or other assemblies may extend through the wall, and if uninsulated may be cold, wet, and frosted. Since wood has some insulating value, the studs and rafters in wood-framed buildings have not caused problems when used for livestock housing.

Consider fire resistance. Some insulation materials are combustible when exposed to high radiant or ambient temperatures, as are some plastic vapor barrier or piping materials. Assurance that the material "will not support combustion" is not enough, unless the material has been rated under conditions equalling a building fire. Noxious gasses and dense smoke are hazards in addition to flame spread.

Table 214-7. Animal heat production.

Type of heat	Animal			
	Sow & Litter ¹	Hogs ²	Poultry ³	Dairy Cattle ⁴
Sensible heat (Q_s)	320 Btu/hr cwt	293 Btu/hr cwt	31.2 Btu/hr bird	230 Btu/hr cwt
Latent heat (Q_L)	205	127	13.0	110
Total heat (Q_A)	525	420	44.2	340

1. At 60°F temperature inside building.
2. At 50°F building temperature and 150 lb animal.
3. For 5 lb bird at a building temperature of 55°F.
4. For dairy cattle in general at 50°F building temperature.

Table 214-8. Approximate ventilation rates.

Minimum (winter)

Hogs.....3 air changes per hour
 Dairy 6 air changes per hour
 Poultry 30 cubic feet per hour per bird

Summer

Hogs.....60 to 90 air changes per hour
 Dairy 24 air changes per hour
 Poultry 300 cubic feet per hour per bird

Sample Problem

The design procedure for temperature balance may be best illustrated by using a sample problem. Assume a swine farrowing building as sketched below. Outside temperature will be -10°F .

24' x 36' 14—sow farrowing house

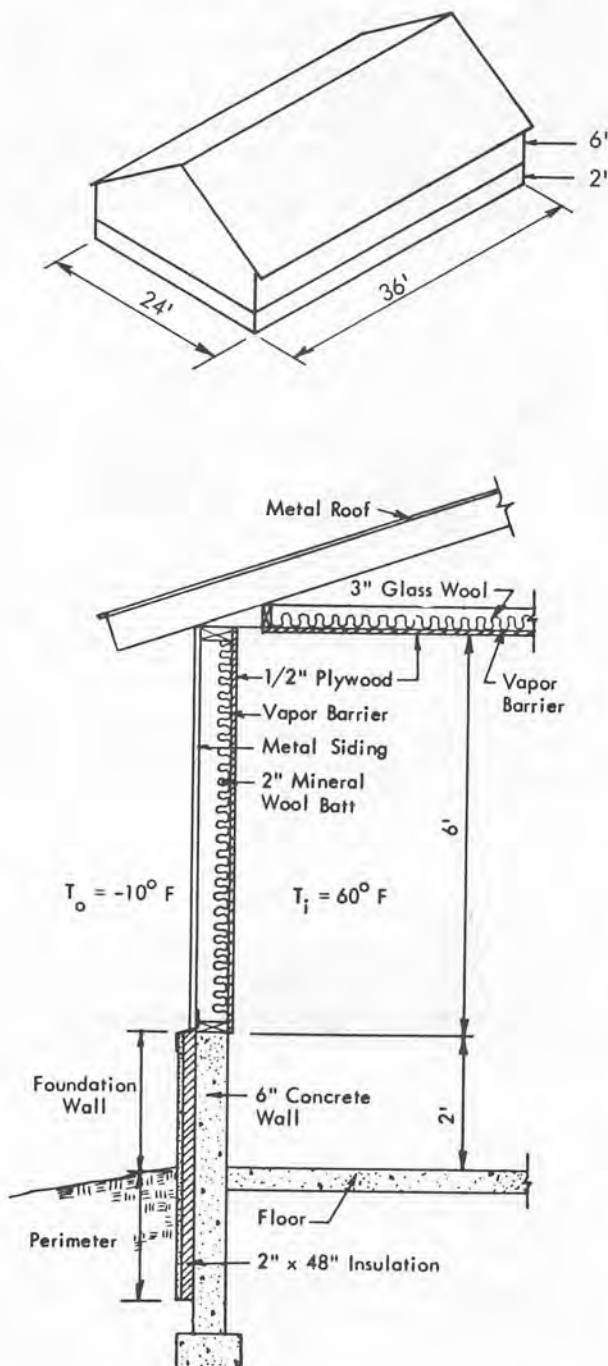


Fig 214-8. Sample problem—farrowing house.

Step I

List the length, width, wall height, and foundation height and calculate and record the linear feet of wall, wall area, foundation area, and ceiling area. The resistance of the frame wall is calculated as follows from Table 214-1:

Number 7. inside surface	0.68
4. 1/2" plywood	0.63
1. 2" wool (2 x 3.7)	7.40
6. air space	0.90
metal is zero	0
7. outside surface	0.17
	9.78

R for the 6" concrete foundation wall with 2" exterior insulation is 8.50 as found in Table 214-2. Note: If concrete is uninsulated, $R = 0.48 + 0.85$ (2 air films) = 1.33, and heat loss is 12,600 Btu/hr instead of 1976 Btu/hr.

R for the ceiling is 13.94 from item 4, Table 214-5.

Step II

The heat losses, q , for the ceiling, walls, foundation, and perimeter are found by placing the appropriate values from Step I into the equations and multiplying.

The 2.22 in the perimeter equation assumes 2" x 24" polystyrene perimeter insulation. Table 214-5, No. 12.

The heat loss, q_b , from the building is a sum of the ceiling, wall, foundation and perimeter losses.

Step III

The ventilation losses, q_v , are based upon the volume of air moved and the temperature differential. The volume of air is the building volume ($L \times W \times H$) times the recommended minimum ventilation as found in Table 214-7 (assume a well-constructed tight building so that there is no leakage around doors and windows). Entering these values in the q_v equation will give the ventilation heat loss. The 0.018 constant in the equation accounts for the specific heat of air (0.24 Btu/lb da) and the specific volume of air (0.075 lb/cu ft).

Step IV

The total heat loss, q_T , is the sum of q_b from Step II and q_v from Step III.

Step V

The sensible animal heat produced, q_a , is as discussed in Chapter 213 and as outlined on the Work Sheet. Assume 330-pound sows.

Step VI

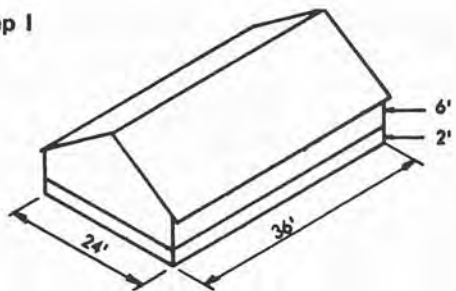
The supplemental heat required, q_s , is the difference between the total heat loss, q_T , in Step IV and the total sensible heat produced, q_a , in Step V.

From the example we found that we needed 26,591 Btu/hr of supplementary heat. The heating unit to install in this building should have a minimum heat output of about 27,000 Btu/hr.

If electric heat is desired, divide the supplementary heat by 3,413, giving the kilowatt hours needed. For our example above, $26,591 \div 3,413 = 7.8$; therefore the electric heater should have a minimum size of 8 Kw-hr.

WORK SHEET—HEAT LOSS

Step I



Building Dimensions -- feet

Length =	<u>36</u>
Width =	<u>24</u>
Wall height =	<u>6</u>
Foundation height =	<u>2</u>
Linear feet of wall (also foundation) =	<u>120</u>
Ceiling area =	<u>864</u>
Wall area =	<u>720</u>
Foundation area =	<u>240</u>

R Values

Ceiling =	<u>13.94</u>
Wall =	<u>9.78</u>
Foundation =	<u>8.50</u>
Perimeter =	<u>2.22</u>

$t_o =$	<u>-10</u> °F
$t_i =$	<u>60</u> °F
temp diff (Δt) =	<u>70</u> °F

Step II

Heat loss due to building (Q_B)

$$Q_{\text{Ceiling}} = \frac{(\Delta t) \text{ times (Ceiling area)}}{(R \text{ ceiling})}$$

$$Q_C = \frac{(70) \times (864)}{(13.94)} = \underline{4,339} \text{ Btu/hr}$$

$$Q_{\text{Walls}} = \frac{(\Delta t) \text{ times (Wall area)}}{(R \text{ wall})}$$

$$Q_W = \frac{(70) \times (720)}{(9.78)} = \underline{5,153} \text{ Btu/hr}$$

$$Q_{\text{Foundation}} = \frac{(\Delta t) \text{ times (Foundation area)}}{(R \text{ foundation})}$$

$$Q_F = \frac{(70) \times (240)}{(8.50)} = \underline{1,976} \text{ Btu/hr}$$

$$Q_{\text{Perimeter}} = \frac{(\Delta t) \text{ times (Linear feet of wall)}}{(R \text{ perimeter})}$$

$$Q_P = \frac{(70) \times (120)}{(2.22)} = \underline{3,780} \text{ Btu/hr}$$

$$Q_B = Q_C + Q_W + Q_F + Q_P = \underline{\underline{15,248}} \text{ Btu/hr}$$

Step III

Heat loss due to ventilation (Q_V)

$$Q_V = (\text{cu ft air/hr}) \text{ times } (\Delta t) \text{ times } (0.018)$$

$$(\text{cu ft air/hr}) = (L \times W \times H) \text{ times (air changes/hr)}$$

$$(\text{cu ft air/hr}) = (36 \times 24 \times 8) \times (3) = \underline{20,736} \text{ ft}^3/\text{hr}$$

$$Q_V = (20,736) \times (70) \times (0.018) = \underline{\underline{26,127}} \text{ Btu/hr}$$

Step IV

Total heat loss (Q_T)

$$(Q_T) = Q_B + Q_V = \underline{\underline{41,375}} \text{ Btu/hr}$$

Step V

Total heat produced, $Q_S = (Q_S \text{ from Table VII}) \text{ times (number of animals) times (cwt per animal)}$

$$= (320) \times (14) \times (3.3) = \underline{14,784} \text{ Btu/hr}$$

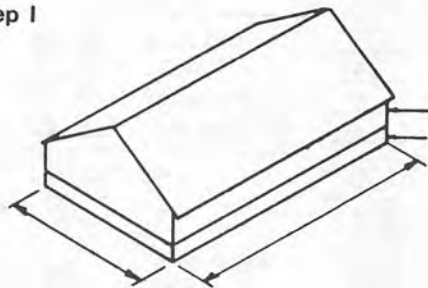
Step VI

Amount of supplemental heat required (Q_{SR})

$$Q_{SR} = Q_T - Q_S \quad Q_{SR} = (41,375) - (14,784) = \underline{\underline{26,591}} \text{ Btu/hr}$$

WORK SHEET -- HEAT LOSS

Step I



Building Dimensions -- feet

Length = _____
 Width = _____
 Wall height = _____
 Foundation height = _____
 Linear feet of wall
 (also foundation) = _____
 Ceiling area = _____
 Wall area = _____
 Foundation area = _____

R Values

Ceiling = _____
 Wall = _____
 Foundation = _____
 Perimeter = _____
 t_o = _____ °F
 t_i = _____ °F
 temp diff
 (Δt) = _____ °F

Step II

Heat loss due to building (Q_B)

$$Q_{\text{Ceiling}} = \frac{(\Delta t) \text{ times (Ceiling area)}}{(R \text{ ceiling})}$$

$$Q_C = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_{\text{Walls}} = \frac{(\Delta t) \text{ times (Wall area)}}{(R \text{ wall})}$$

$$Q_W = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_{\text{Foundation}} = \frac{(\Delta t) \text{ times (Foundation area)}}{(R \text{ foundation})}$$

$$Q_F = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_{\text{Perimeter}} = \frac{(\Delta t) \text{ times (Linear feet of wall)}}{(R \text{ perimeter})}$$

$$Q_P = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_B = Q_C + Q_W + Q_F + Q_P = \underline{\underline{\quad \text{Btu/hr}}}$$

Step III

Heat loss due to ventilation (Q_V)

$$Q_V = (\text{cu ft air/hr}) \text{ times } (\Delta t) \text{ times } (0.018)$$

$$(\text{cu ft air/hr}) = (L \times W \times H) \text{ times (air changes/hr)}$$

$$(\text{cu ft air/hr}) = (\quad \times \quad \times \quad) \times (\quad) = \quad \text{ft}^3/\text{hr}$$

$$Q_V = (\quad) \times (\quad) \times (\quad) = \underline{\underline{\quad \text{Btu/hr}}}$$

Step IV

Total heat loss

$$(Q_T) = Q_B + Q_V = \underline{\underline{\quad \text{Btu/hr}}}$$

Step V

Total heat produced, $Q_S = (Q_S \text{ from Table VII}) \text{ times (number of animals) times (number of cwt per animal)} = (\quad) \times (\quad) \times (\quad) = \quad \text{Btu/hr}$

Step VI

Amount of supplemental heat required (Q_{SR})

$$Q_{SR} = Q_T - Q_S \quad Q_{SR} = (\quad) - (\quad) = \underline{\underline{\quad \text{Btu/hr}}}$$

CHAPTER 215 VENTILATION SYSTEMS

The Ventilation Process

Fresh air is made up principally of these gases:

Nitrogen (N ₂)	78%
Oxygen (O ₂)	21%
Carbon Dioxide (CO ₂)	
and rare gases	Less than 1%

If air is not replaced in livestock housing, the air composition will change, and the concentration of carbon dioxide and other harmful gases will increase to the danger level. Carbon dioxide, while essential to trigger breathing processes, becomes noxious at high concentrations. Research has shown that the critical level of some gases in air for sustaining the life of chickens is:

Gas	Symbol	Lethal	Tolerable
Carbon Dioxide	CO ₂	Above 30%	Below 1%
Methane	CH ₄	Above 5%	Below 5%
Ammonia	NH ₃	Above 0.05%	Below 0.004%
Hydrogen Sulfide	H ₂ S	Above 0.05%	Below 0.004%
Oxygen	O ₂	Below 6%	Above 16%

Source: University of Kentucky

According to these data, the minimum safe biological rate of ventilation for layers is 1 cfm/50 birds. By comparison, 4 cfm/person is required in a crowded room. Greater rates are desirable for optimum performance.

Air exchange

As the ventilation system exchanges air it brings in oxygen needed to sustain life and carries out harmful gases and undesirable odors. It also dilutes air-borne disease organisms.

Air also absorbs and carries sensible heat and moisture.

Moisture exchange

A primary purpose of winter ventilation is to remove excess moisture vapor from the building. When heated, air expands in volume and can hold more moisture—about twice as much for each 20°F rise in temperature. These properties are shown schematically in Fig 215-1 & 2.

Heat exchange

When ventilation air entering a building is cooler than inside air, it removes sensible heat from the building. Each 12 to 14 cu ft of ventilation air absorbs ¼ Btu of heat for each degree it is warmed. In warm weather, more air is moved through the buildings to remove excess heat, since each cu ft of the warmer air absorbs less heat than cooler air. Conversely, in cold weather, the rate of air movement is reduced to prevent over-cooling.

Sensible heat is removed from air that evaporates water. Water's heat of vaporization is about 1000 Btu/lb (or pint) of water evaporated. Some heat is absorbed by ventilation air as moisture is evaporated from floors, bedding or litter. To conserve heat in winter, keep floors as dry as

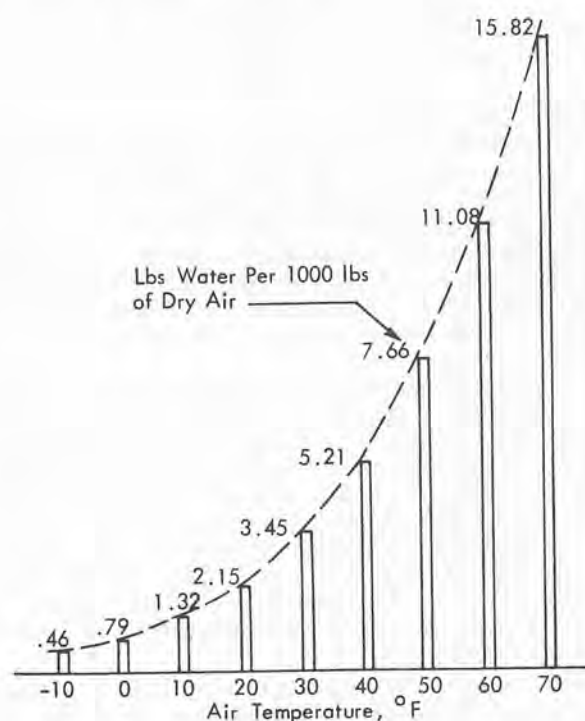


Fig 215-1. Moisture holding capacity of air.

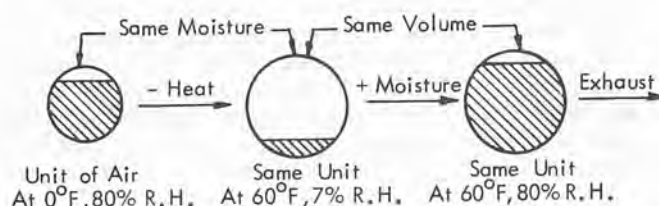


Fig 215-2. Cold air expands as it is heated and can absorb more moisture.

possible. Permitting high relative humidities in a building during winter can reduce the sensible heat load and reduce dustiness, but more condensation on building surfaces will also result.

It is possible to over dry—in broiler houses the brooder heating and ventilation systems can over dry the litter, creating a dusty atmosphere.

Climate

Winter ventilation

The removal of moisture and odor places the greatest demand on the winter ventilating system. Since ventilation also transfers heat, the quantity of air must be controlled to meet the combined requirement for removing moisture and controlling temperature. In winter it is important to conserve the heat produced in a building to reduce the need for supplemental heat. Ventilation is therefore either a balance or a compromise between the minimum

rate necessary to remove moisture and the maximum that can be permitted to control temperature.

Adult animals may produce sufficient heat in winter, except perhaps in sub-zero temperatures; but youngstock usually require supplemental heat.

Summer ventilation

The major requirement for summer ventilation is to make the best of a bad thing—temperatures above the comfort zone for most livestock—which requires several times the winter air movement rates unless artificial cooling is used. Summer ventilation is also affected by insulation, which reduces heat gain through the building surfaces, but also slows night cooling when outdoor temperatures are lower than indoor.

With uncooled air, the minimum inside temperature possible, late on a hot afternoon, is the outside temperature in the shade. With good design, inside temperatures are lower than outside during the morning, and will rise to no more than 2°-3°F above outside in the afternoon and evening.

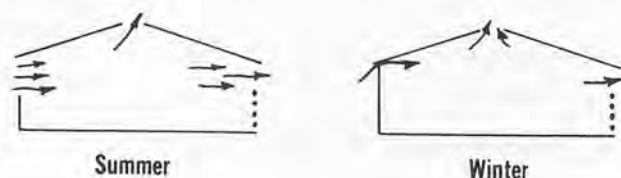
In addition to forced ventilation, use natural ventilation by opening large windows and doors. High air velocities usually cause no animal discomfort, since the difference between inside and outside temperatures is small.

Refrigerated air cooling has not been economical for most livestock buildings. But, artificial zone cooling is used for farrowing units with refrigerated air ducted to the sows' heads.

Some of the sensible heat in the air is converted into latent heat in evaporative cooling installations. This method works best in very dry climates, will not work when the outside air is already nearly saturated, and may raise humidities to levels as damaging as high temperatures. Sprinkling water can help keep some livestock more comfortable in hot weather by evaporation from the body surface.

Buildings Kept Cold In Winter

Buildings designed to use natural air movement maintain inside temperatures within a few degrees of outside conditions.



Open shelters do not require the ventilation refinements of enclosed buildings. But, provide adequate openings—inlets and outlets—for good air circulation. In cold weather air circulation prevents moisture condensation under the roof, and in hot weather, it keeps inside temperatures acceptable.

At least minimum insulation, 1", is recommended in the roof. Roof the entire animal area, especially in cold and snowy regions.

Openings

Leave front wall, S or E open. Provide small openings in back wall, N or W, for winter inlets: 4"-6" continuous slot under eave, or equivalent. Fig 215-3.

Install large openings (doors or ventilation panels) in back wall for summer inlets. About 1/3-1/2 of the wall area should be open; breezes should circulate at animal level. Fig 215-4.

Provide a continuous slot at the ridge. Slot width should be about 1" for each 10' of building width, with a 6" slot recommended in the cold zone to avoid frost accumulation. Fig 215-5.

Snow and wind control

Snow drifting and cold winds can be reduced inside open-front shelters. Use local practice and experience to face the open front away from major winter storms.

Pen partitions can be solid to reduce drafts along the length of the building, but should not block summer breezes. In colder climates, some cross partitions, solid to the roof and spaced about 2-1/2 times the span apart, will reduce drafts. Fig 215-6.

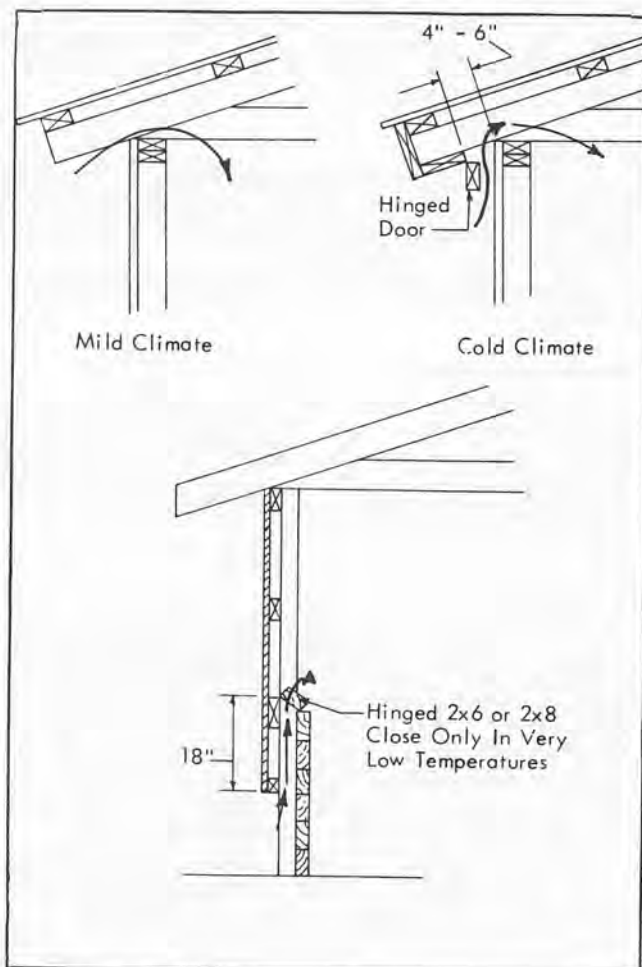


Fig 215-3. Winter inlets.

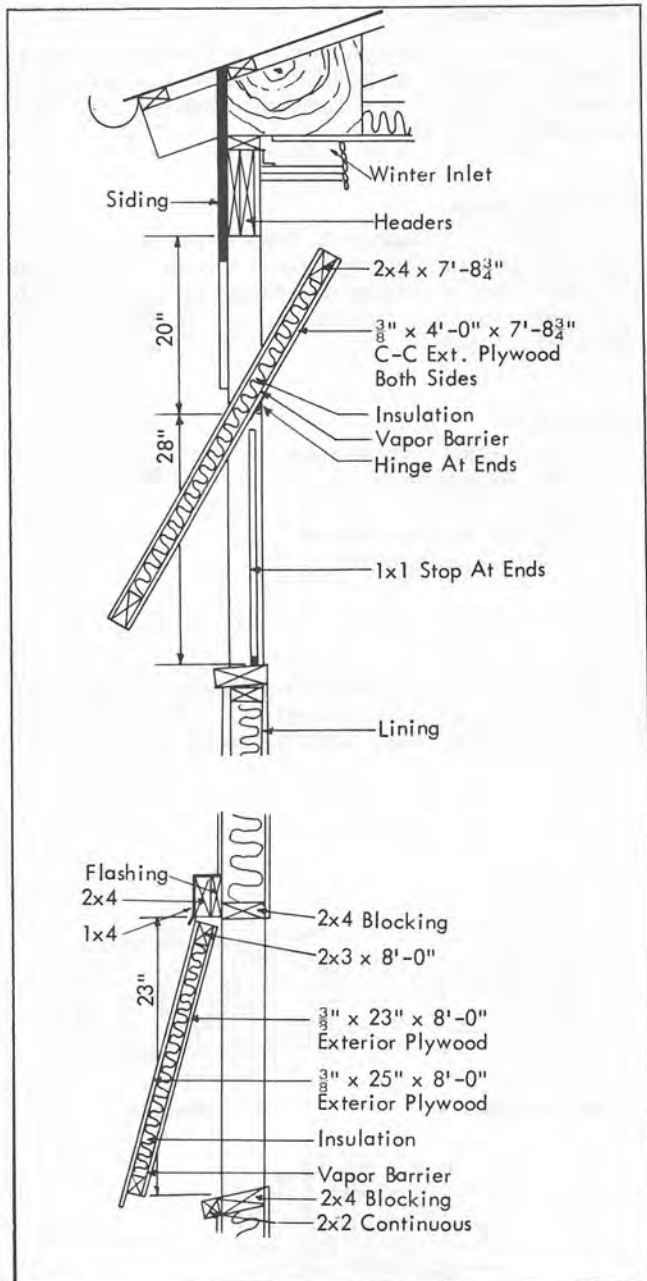


Fig 215-4. Doors for summer ventilation.

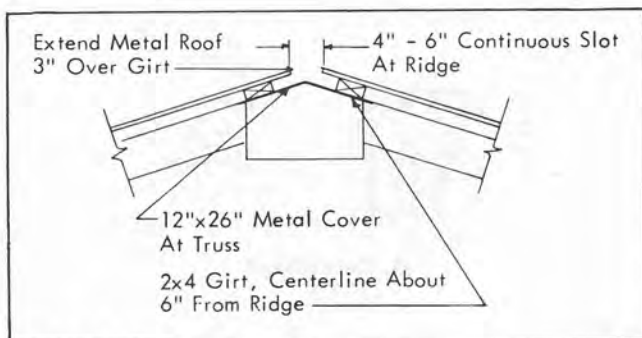


Fig 215-5. Ridge outlet.

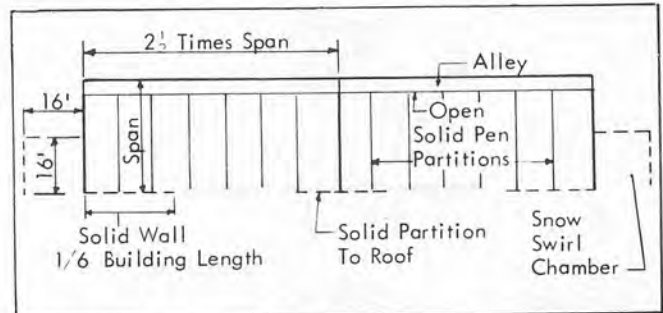


Fig 215-6. Snow and wind in open buildings.

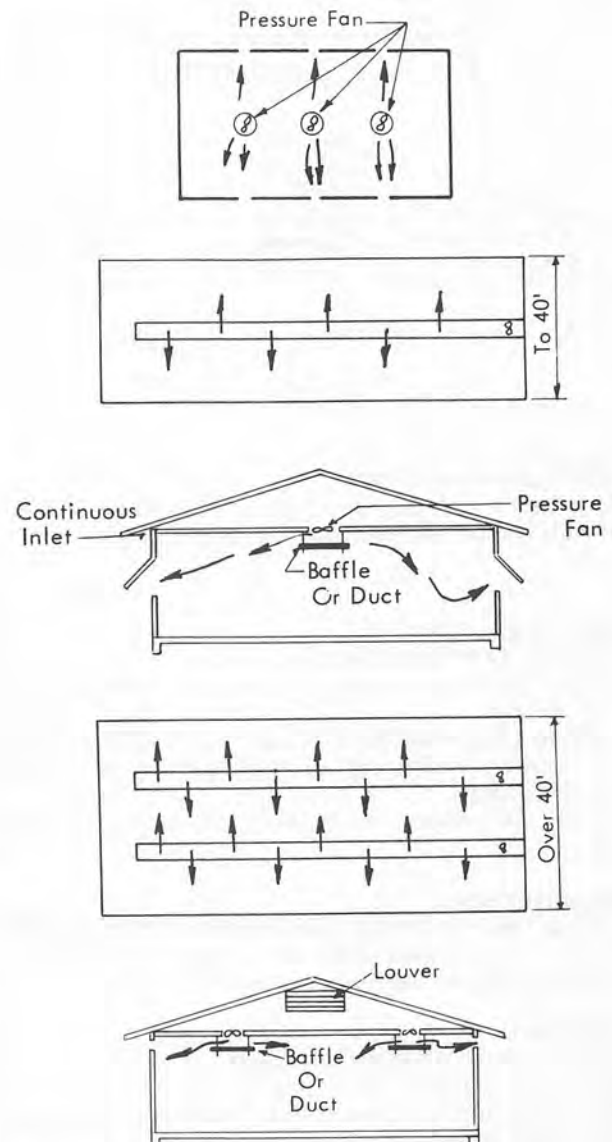


Fig 215-7. Pressure fan locations.

For small buildings, install one fan, or one fan at each end of building. See duct design. For narrow buildings, install fan duct or baffle in center; for wide buildings space fan duct or baffles about 20' apart.

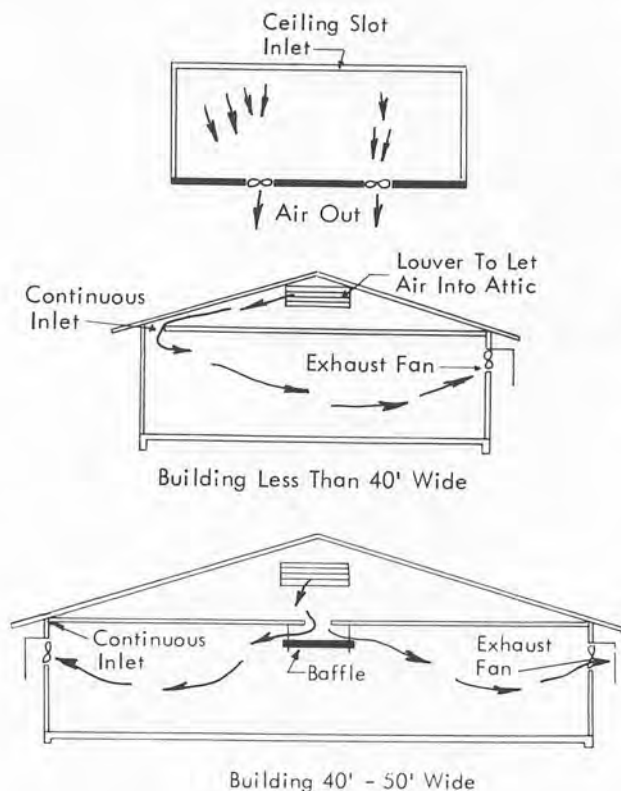


Fig 215-8. Exhaust fan locations.

Use a center diffusing inlet when the building is 40'-50' wide. Install two inlets for widths over 50'.

Cold, windy region

Reduce front wall opening:

Side part way down the wall to reduce snow blow-in.

Close front wall for 1/6 building length at each end and adjacent to solid partitions in long buildings.

Provide 16' square snow swirl chambers at each end.

Moderate region

Limit roof overhang, leaving front open as high as possible, because sunshine along the open front is of more value than reduced snow blow-in.

Mild region

Leave front wall completely open.

Solid cross-partitions may not be needed.

Roof overhang to cover feeder, or handling alley, may be provided.

Mechanical Ventilation

There are two main types of mechanical ventilation systems:

- pressure systems
- exhaust systems

Pressure systems

In pressure systems, the fans blow air into the building, creating a positive indoor pressure that pushes air out of the building through the outlet openings. Fig 215-7.

Exhaust systems

In exhaust ventilation, fans expel air from the building; they create a partial vacuum inside the building. The pressure difference between outside and inside pushes ventilation air in through the inlets. Fig 215-8.

Components

A mechanical ventilation system is made up of three main components:

- Fans
- Air distribution systems
- Controls to regulate fans

Fans

Types

Fans move the required ventilation air through the building, and are divided into two main types: axial flow fans, and centrifugal fans. Fig 215-9.

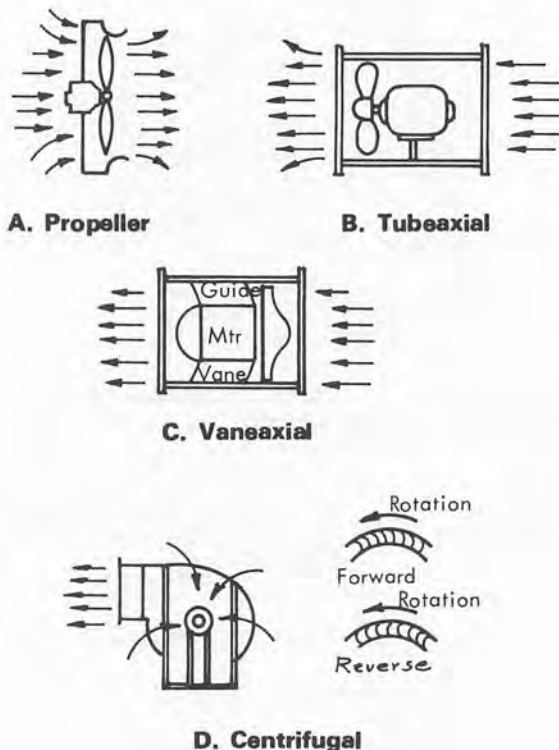


Fig 215-9. Types of fans.

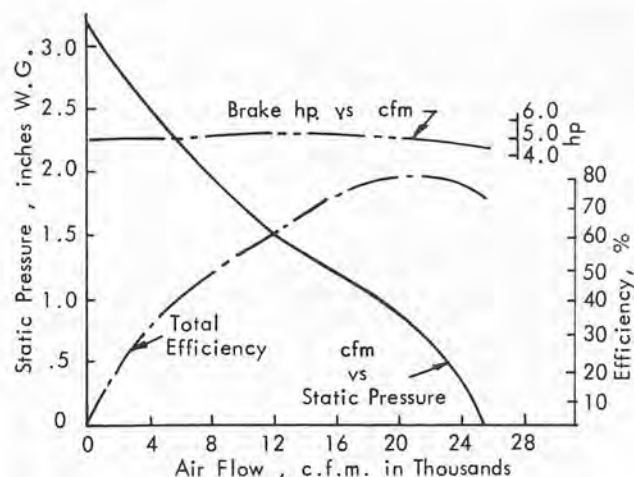


Figure 215-10. Sample performance curves.

Motors and drives

Fan motors should be:

- totally enclosed for dust protection,
- able to operate continuously and at all times,
- equipped with overload protection.

There are several types of fan motors, including capacitor-start, two speed, and variable speed.

Fans can be direct or belt-driven.

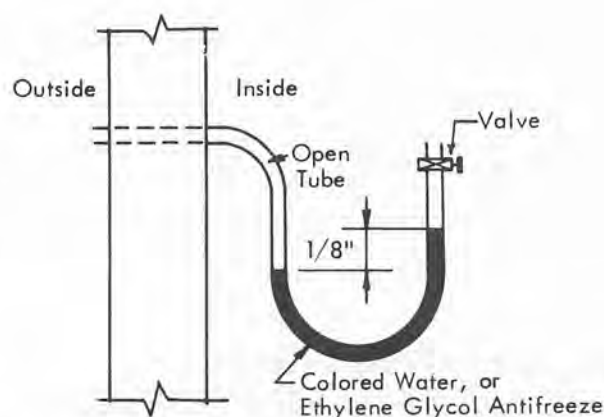


Fig 215-12. This water column illustrates the pressure difference of 1/8" between inside and outside when exhaust fans are operating.

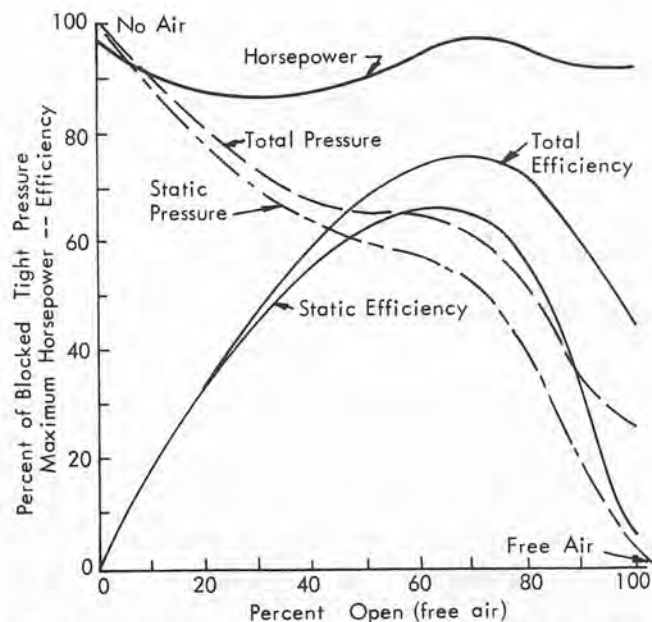


Fig 215-11. Operating characteristics of a typical axial flow airfoil fan.

Ratings

The Air Moving and Conditioning Association Inc. has set up standard tests and procedures. "A.M.C.A." fan ratings and performance charts certify a fan will deliver the volume of air specified

for the static pressure and with the accessories in place as listed or illustrated in the certification. Such accessories as back-draft shutters, fan guards, and hoods offer resistance and may collectively increase static pressure as much as 1/8" water gage (W.G.).

Static pressure is the difference in atmospheric pressure between the inside and the outside of the building measured in inches of water column or water gage. It indicates the resistance which fans must overcome to move air through the building. Fig 215-12.

Ventilation systems for farm buildings are usually designed for static pressures of about 1/8" W.G.

If a system uses both pressure evaporative coolers and exhaust fans, as in a hog house, the maximum air delivery is the capacity of the exhaust fans at 0" W.G.

Install each fan with an individual time-delay fuse to protect against burned-out motors and electrical overloads, especially when the equipment is automatically controlled. Table 215-2.

Recommended wire sizes for various lengths of wire and sizes of fan motor are in Table 215-3.

Selection

Select a fan by its ability to deliver air at the anticipated static pressure—not on its diameter or number of blades. Also consider:

- rust resistant blades
- a smooth streamlined ring around the blade tips
- size and type of shutters
- type of motor

Speeds of belt driven fans may be varied with a step pulley or a variable sheave pulley. Obtain air-flow and horsepower data for each fan speed. Direct-driven fans generally require less maintenance and have less power transmission loss than belt driven.

Table 215-1. Typical fan performance data—single speed, single volume fans.

Fan		Fan capacity, cfm		
Speed rpm	Size in.	Free Air	At .10" W.G.	Motor h.p.
1725	14	1620	1400	1/6
1140	18	2333	1956	1/6
1725	18	2500	1900	1/6
1725	18	3530	3330	1/3
1140	24	4930	4280	1/4
1725	24	5485	5100	1/3
794	30	6718	5820	1/3
906	30	7670	6880	1/2
613	36	9010	7550	1/3
695	36	10190	9000	1/2
538	42	12521	10580	1/2

phenomenon, the vena-contracta effect, increases the velocity of the air emerging from the opening. To determine the velocity, V_i , of the air issuing from an opening of area, A_i :

$$V_i = \text{cfm}/60\%A_i \quad \text{Eq 215-1}$$

• Air flow in room air

Several parameters describe air distribution of a ventilation system; the most important are:

- Residual velocity ratio, V_x/V_i , relates the residual velocity, V_x , at any distance, x , measured along the air stream, to the inlet velocity, V_i .
- Throw, x , is the distance along the line of maximum air velocity, from the inlet to the

Table 215-2. Ampere rating for time-delay fuses.

Hp	115 Volts	230 Volts
1/6	5	2.5
1/4	7	3.5
1/3	9	4.5
1/2	12	5.6
3/4	15	8
1	20	10
1 1/2	25	12

Table 215-3. Wire sizes for individual single-phase motors (Based on 3 percent voltage drop).

Motor Hp	Volts	Full-load Current*	Length of Run in Feet					
			50	75	100	150	200	250
1/6	115	4.4	14	14	14	12	10	10
1/4	115	5.8	14	14	12	10	10	8
1/3	115	7.2	14	12	12	10	8	8
1/2	115	9.8	14	12	10	8	8	--
3/4	115	13.8	12	10	8	8	--	--
1/6	230	2.2	14	14	14	14	14	14
1/4	230	2.9	14	14	14	14	14	14
1/3	230	3.6	14	14	14	14	14	14
1/2	230	4.9	14	14	14	14	14	12
3/4	230	6.9	14	14	14	12	12	10
1	230	8.0	14	14	14	12	12	10
1 1/2	230	10.0	14	14	14	12	10	10

*Table 430-148, National Electrical Code 1965.

Air Distribution Fundamentals

Uniform air distribution is a major objective of livestock ventilation systems. Some of the theory and practice of air distribution in a ventilated space follows.

Air distribution

• Air flow through an opening

When air flows through any opening of any shape, the crosssection area of the issuing jet is reduced to 60%-80% of the total free area of the opening—60% is a reasonable design value. This

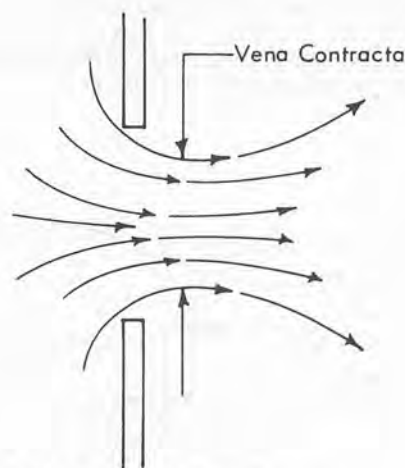


Fig 215-13. Air flow through an opening.

point where some predetermined air velocity is reached.

- Entrainment ratio, E_x , is the quantity of room air entrained by the air stream jet along x ft of jet, divided by the quantity of air through the inlet during the same time.

The residual velocity ratio indicates stream velocity decay along the jet, and can predict drafts. The entrainment ratio measures mixing of room air with ventilation air. Higher entrainment ratios mean better mixing, better moisture and odor removal, and more uniform conditions throughout the ventilated space.

• Entrainment of room air

An air jet stirs and entrains some room air along the entire length of the active part of the jet. Fig 215-14.

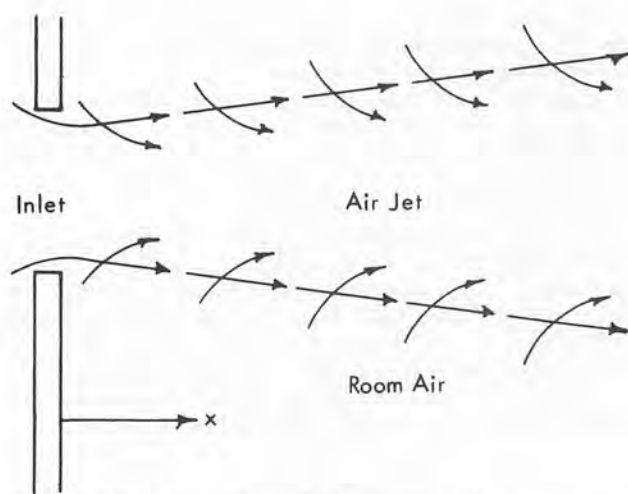


Fig 215-14. Entrainment of room air by a ventilating jet.

The entrainment ratio at a point x ft from the inlet is:

$$E_x = (Q_x - Q_i) / Q_i \quad \text{Eq 215-2}$$

$$\text{ratio} = (\text{cfm} - \text{cfm}) / \text{cfm}$$

where:

- Q_i = ventilation rate through the inlet.
 Q_x = total volume of air flowing in the jet at the point under consideration.

Ceiling Fan Baffle

Fix a square baffle 2"-3" below a ceiling-mounted fan to deflect the air stream. Make the baffle slightly larger than the fan diameter, and install it with the sides at 45° to the sidewall. The fans are arranged along the centerline of the ceiling and spaced about the building width apart. Typical air patterns are shown in Fig 215-17 & 18. The air flow tends to create air curtains at a vertical plane midway between two fans. Air moves down these curtains and down the walls, and then inward toward the fans across the floor.

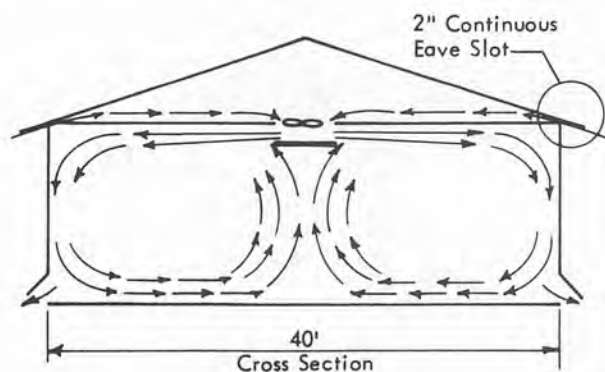


Fig 215-17. Air distribution with a ceiling baffle.

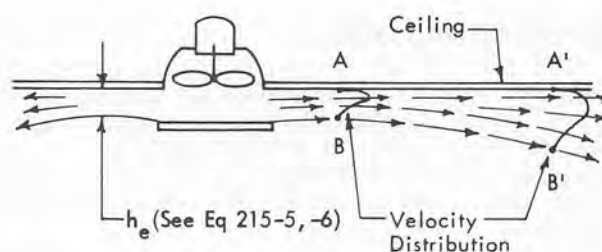


Fig 215-18. Typical jet from a ceiling baffle.

Residual velocity and entrainment ratio of a baffle jet are given by:

$$V_x = V_i 1.075e^{-0.0408(x/h_e)} \quad \text{Eq 215-5}$$

$$E_x = 0.1 x/h_e - 0.09 \quad \text{Eq 215-6}$$

where:

- V_x = residual velocity, fpm.
 V_i = the initial velocity of the jet
 x = distance from center of baffle, ft.
 h_e = the effective height of the jet leaving the baffle, ft.
 E_x = entrainment ratio.

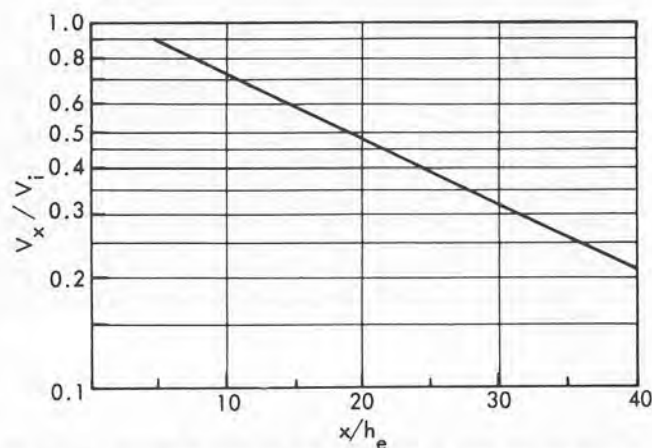
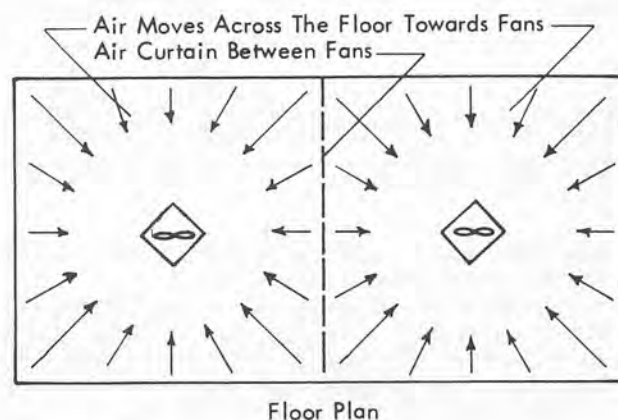


Fig 215-19. Residual jet velocity from a ceiling baffled fan. See Eq 215-5.



Floor Plan

Air Inlets And Outlets

The rate of air change is determined by fan delivery, but the uniformity of air distribution depends on the location, design and adjustment of the air inlets. This is true of both exhaust and pressure systems, assuming that the longest path of air from inlet to outlet does not exceed about 100 feet.

The total area of air inlet must be proportional to total fan capacity.

$$Q = AV \quad \text{Eq 215-7}$$

$$\text{or } A = Q/V \quad \text{Eq 215-8}$$

where:

Q = ventilation rate, cfm.

A = inlet area, sq ft.

V = air velocity, fpm.

A common rule of thumb sizes air inlets at 1 sq in of area for each 4 cfm of fan capacity, which makes the velocity about 575 fpm. But, the pressure drop across the inlet affects fan performance and therefore capacity.

Tests at Penn State University determined the relationship between the dimensions of slot inlets and the volume of air admitted at various pressure differentials. The air flow rate at a constant pressure differential is proportional to the width of the slot. The rate through a 4" wide slot at 0.04" W.G. is 200 cfm—4 times the flow through a 1" slot at the same W.G. This relationship holds at the higher pressure difference of 0.125" W.G. However, increasing the pressure difference across the slot about three times (0.04 to 0.125") results in only doubling the rate of flow through the slot. Inlet velocities can be predicted at $V = \text{cfm}/A = 600 \text{ fpm @ } 0.04"$ and $1200 \text{ fpm @ } 0.125"$. Table 215-4.

Table 215-4. Rate of air flow through ventilation slots 1 foot long.

Inches Slot Width	Cfm Static Pressure	
	0.04"	0.125"
1	50	100
2	100	200
3	150	300
4	200	400

Source: Pennsylvania State University

Example: Size a slot air inlet for a maximum fan delivery of 50,000 cfm at 0.04" W.G.

Assume a maximum slot width of 3". From Table 215-4, each foot of length of a 3" wide slot will admit air at the rate of 150 cfm at 0.04" W.G. Therefore the needed slot length is $50,000/150 = 334'$ long. If the W.G. is increased to .125" then only 167' of 3" slot is needed ($50,000/300 = 167$), or 334' of 1-1/2" slot.

Usually the slot is a little wider than calculated, and the opening width adjusted for desired pressure differential and distribution.

Outlets for a pressure system should be widely dispersed, and sized on the basis of an exit velocity not to exceed 1000 fpm (8-10 mph). This is equivalent to 1 sq ft (144 sq in) of exit area for each 1,000 cfm of fan capacity.

Fans are most efficient if fan housing resistance is low and inlet area (or outlets if pressure system) is large. The maximum resistance housings and inlets in the livestock buildings should not exceed 0.2" W.G. and often will be less than 0.1". Air heaters and filters further increase the resistance.

Fig 215-20 to 215-25 illustrate air distribution for exhaust and pressure ventilation systems.

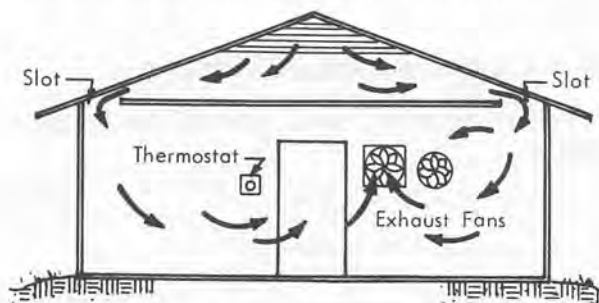


Fig 215-20. Slot inlets and air circulation in a building.

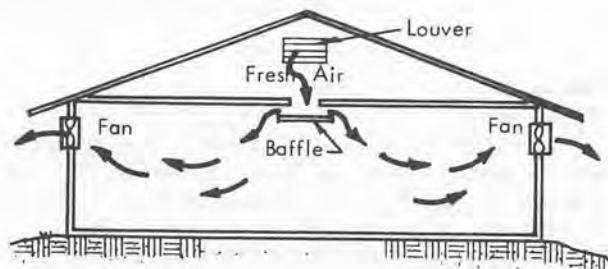


Fig 215-21. Ceiling slot inlet

Fresh air is provided through the gable louver. The slot baffle should be insulated and adjustable.

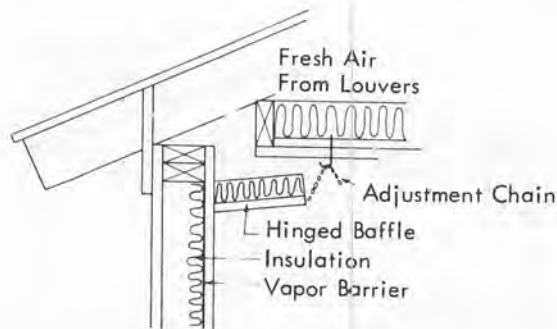


Fig 215-22. Slot inlet with fresh air supplied through the attic.

The hinged baffle allows adjustment of the inlet opening.

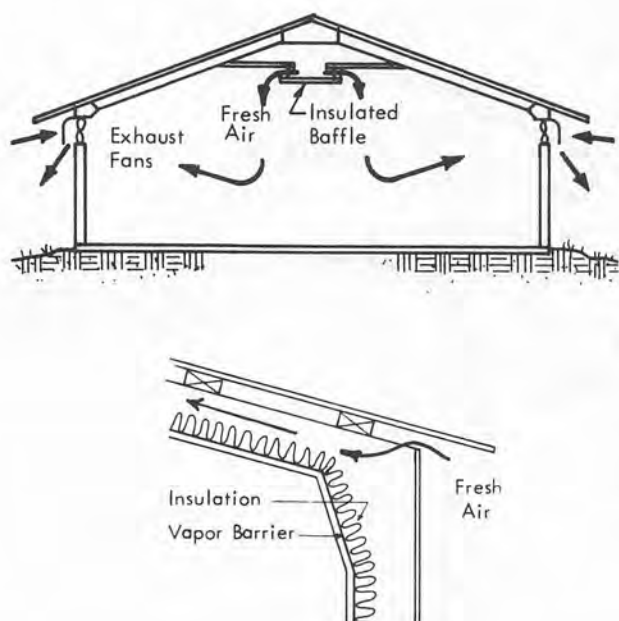


Fig 215-23. Ceiling inlet slot in a rigid frame building.

A fresh inlet under the eave can be used if the roof framing does not obstruct the air passage. When the eave inlet cannot be used, an insulated duct is constructed under the ridge. Air inlets to the duct may be through gable end louvers.

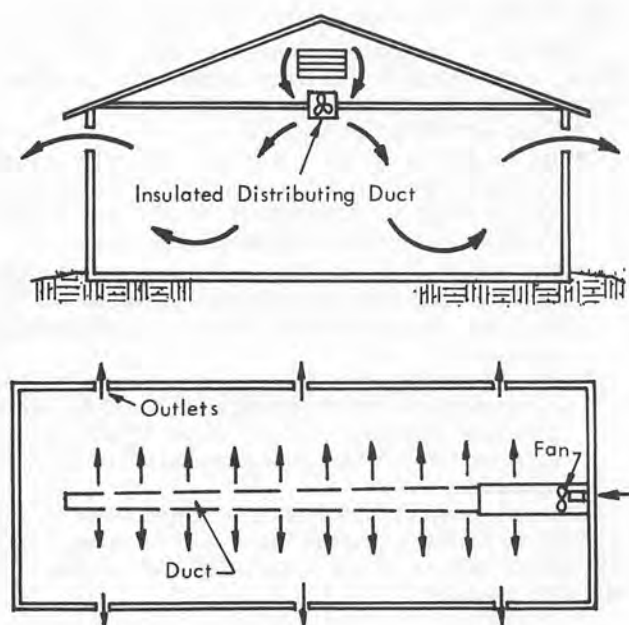


Fig 215-24. Pressure ventilating system with tapered insulated duct. To provide for variable air flow a two-speed fan or two fans will be required.

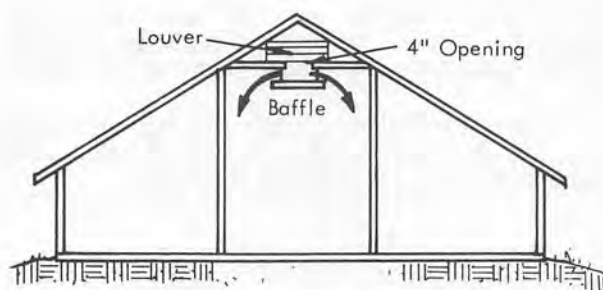


Fig 215-25. Ceiling inlet for remodeling.

When remodeling a building with low side walls a partial ceiling forms an attic space. Install insulation in the walls or ceiling and under the roof.

Circulation fans improve air distribution in winter to aid in drying or heating corners. In summer, they improve animal comfort by increasing air velocity over the skin. Circulation fans can be 1750 rpm unrated units, but should have sealed motors. Provide one 10"-12" swivel-mounted fan for each 50'-60' of wall.

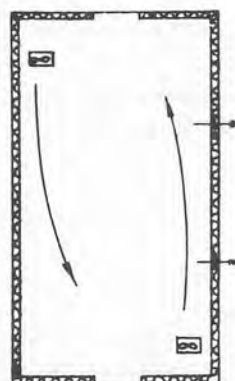


Fig 215-26. Circulating fans.

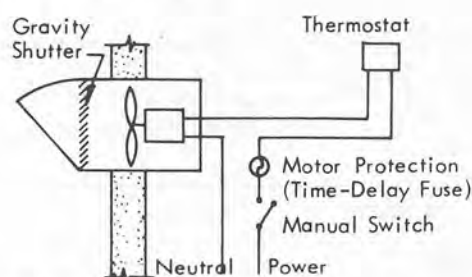


Fig 215-27. Single-speed fan and on-off thermostat.

Duct Inlets

In small buildings where only one fan is needed and a pressure system is desired, a duct will help distribute incoming air. Air delivery from the duct will not be uniform.

Determine fan capacity required, Select a fan to deliver the required cfm at 1/8" static pressure. Make a square duct the size of the fan diameter or larger, or a rectangular duct of the

same area. Provide one 2" hole (round or square) for each 20 cfm fan capacity, spacing holes uniformly down each side of the duct.

To increase delivery from the fan end of the duct, increase the number or size of holes at the fan end and close some at the other end.

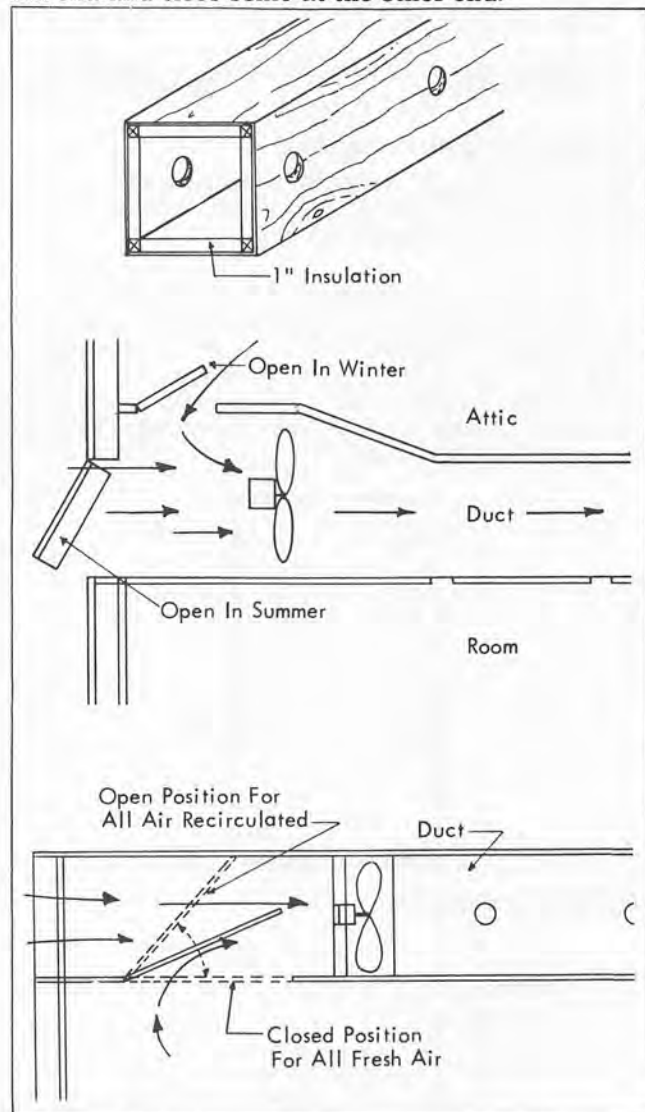


Fig 215-28. Duct inlets.

Duct Outlet

During remodeling and improving an older building in a severe climate, a ventilation system may be needed despite inadequate insulation. To reduce heat loss, ducts may be built over exhaust fans that permit drawing cooler air off the floor during very cold weather, and warmer air near the ceiling during mild or warm weather.

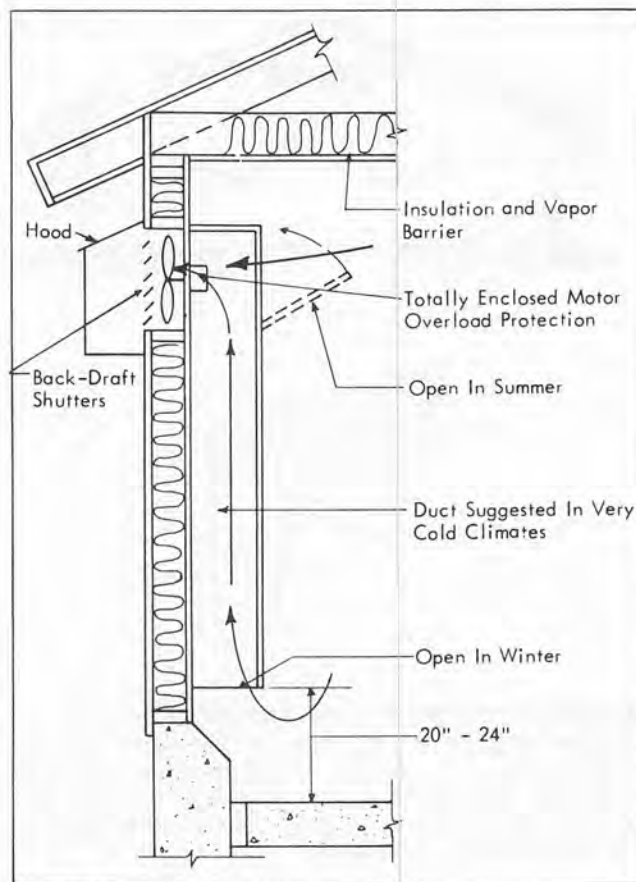


Fig 215-29. Duct outlet.

Ventilation Control And Wiring Systems

Ideally, a ventilation system maintains temperature and relative humidity within the optimum range at all outside weather conditions:

- By controlling fan speeds.
- By partial recirculation of outside air through constant speed, continuously running fans, allowing only a proportion of the air in the building to be passed through the fans.
- By baffling the air through a constant speed fan, by reducing the effective diameter of the fan and therefore the amount of air passing through it.
- By switching the fan on and off either by a time clock or thermostat. The time clock will turn the fan on and off at definite intervals of time, while a thermostat senses temperature.

Several control circuits are illustrated in Fig 215-27 to 215-33. Install each fan on a separate branch circuit, so if one circuit fails, the other fans will still operate.

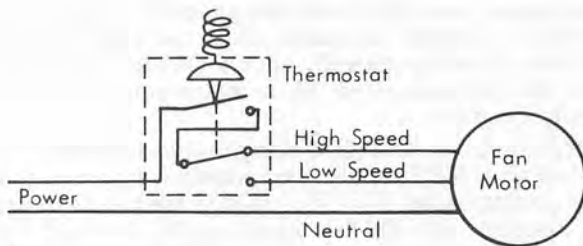


Fig 215-30. 2-speed fan and thermostat.

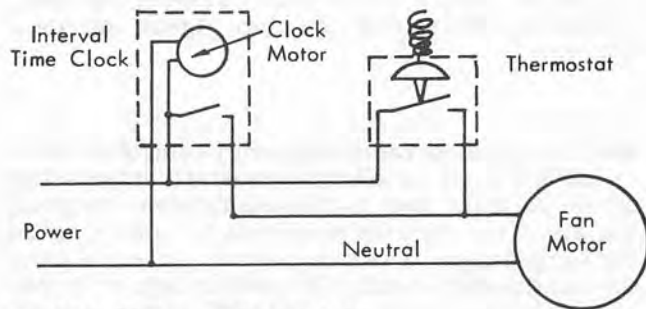


Fig 215-31. Single-speed fan and clock.

An interval timer is set so the fan delivers the minimum volume needed. A thermostat overrides the timer so the fan is on continuously at higher indoor temperatures.

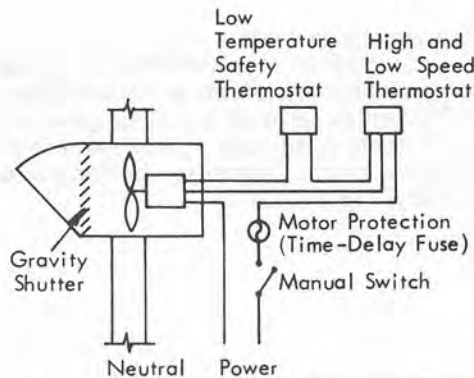


Fig 215-32. 2-speed fan and high-low and low temperature on-off thermostats.

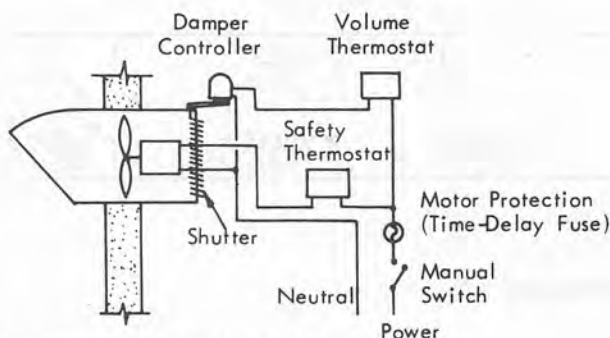


Fig 215-33. Variable air intake system.

A single-speed 2-volume fan is controlled with a thermostat on the shutter-damper, and with a low temperature on-off safety thermostat.

Emergency control systems

If fan failure is known, steps can usually be taken to prevent livestock losses. Fan failure may be due to mechanical and/or electrical reasons. Electrical failure may be caused by such things as blown fuses, loose connections, broken wires, or power outage.

Warning systems cannot protect against all possible causes of fan failure, but the more common causes have been considered. Alarm systems are available commercially. Fig 215-34 to 215-38.

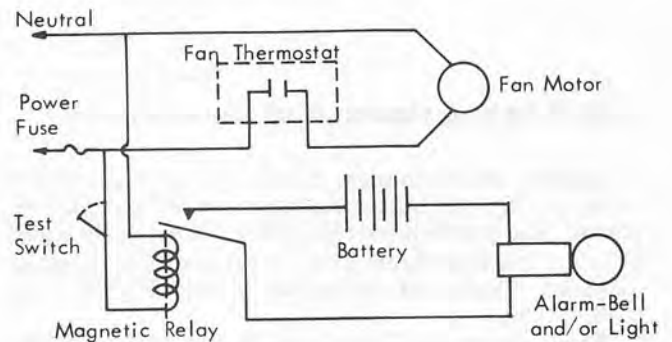


Fig 215-34. Battery operated relay-controlled alarm.

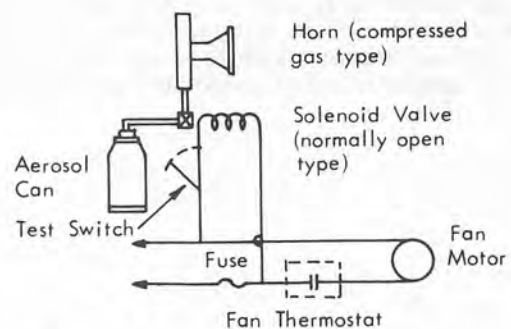


Fig 215-35. Solenoid valve-controlled compressed gas horn.

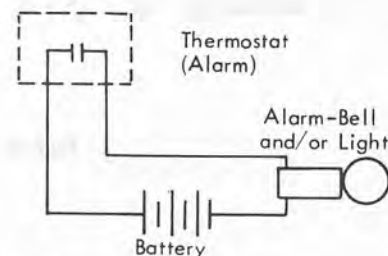


Fig 215-36. Battery-operated, thermostatically-controlled alarm.

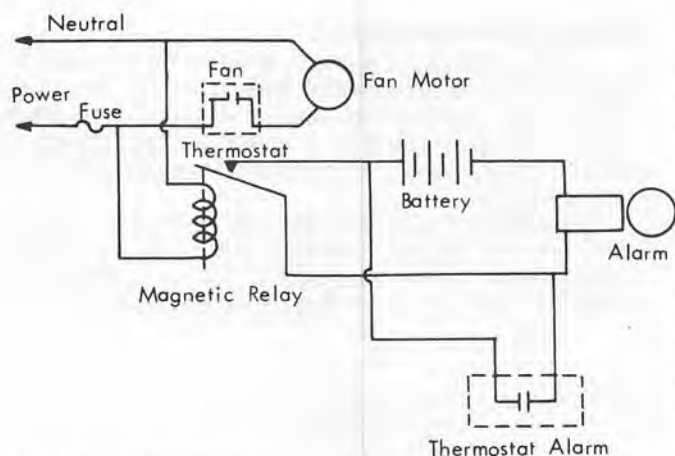


Fig 215-37. Combination temperature- and power-sensitive alarm.

Battery Maintenance. Some systems require a battery. Dry-cell batteries must be periodically replaced, and wet-cell batteries should be kept charged with a trickle-charger. This latter method requires frequent checks to replenish water. Fig 215-34, -36, -37 -38.

Response Time. The alarm shown in Fig 215-34 does not sound until conditions within the confined area are critical. The others respond to power failure.

Battery operated relay-controlled alarm

In Fig 215-34, a magnetic relay is connected to the fan circuit, so the relay is energized when there is power to the fan. The contacts of this normally-closed relay are a switch for a battery operated alarm. Should the power fail, the contacts under spring tension close to sound the alarm. A type of magnetic relay rated at fan voltage for

continuous operation with single-pole, single-throw normally closed contacts may be used. A test switch (normally closed) should be included unless the fan is connected to a disconnect switch or circuit breaker.

Solenoid-valve controlled compressed gas horn

In Fig 215-35, an air horn powered by an aerosol can (compressed gas), commonly used as fog horns or distress signals for small boats, is used with a normally-open solenoid valve. The solenoid valve will be closed as long as there is power to the fan. With an interruption of power, the spring within the valve causes it to open, allowing the compressed gas to operate the horn. Again, include a test switch.

Battery-operated, thermostatically-controlled alarm

In Fig 215-36, a cooling thermostat (contacts close on temperature rise) is the sensing element, giving the alarm on a preset temperature, indicating the air temperature is above normal. In some cases the thermostat should be reset to adjust for seasonal changes—between 80°-90°F under summer conditions, and lowered to 70°-75°F in winter. This system may also indicate when a water spray or sprinkler should be turned on. Test the alarm circuit by changing the thermostat setting.

Combination alarm system

An alarm combining circuits shown in Fig 215-34 and -36 gives added protection. Failure of ventilation due to broken or slipped belts, plugged air ducts, etc., is detected through increased air temperature, while a power failure to the fans is detected immediately. Fig 215-37.

Multiple fan operations

Wiring an alarm system for several fans requires a relay for each fan, but only one alarm. If the combination system is used, a relay is required for each fan and a thermostat for each fan.

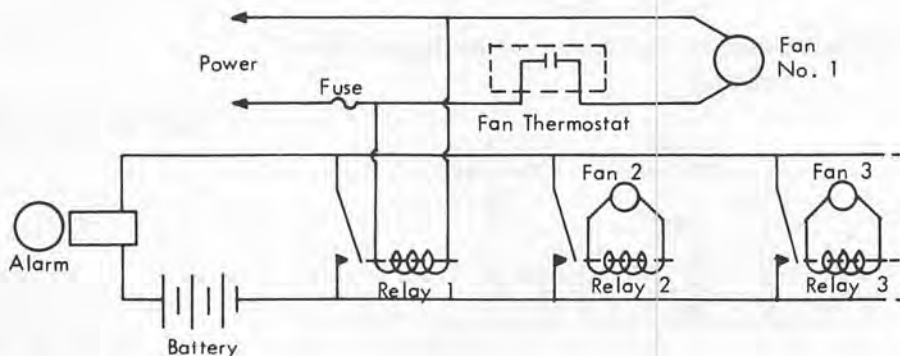


Fig 215-38. Alarm on multiple-fan system.

220 APPLICATIONS

CHAPTER 221 VENTILATION OF SWINE BUILDINGS

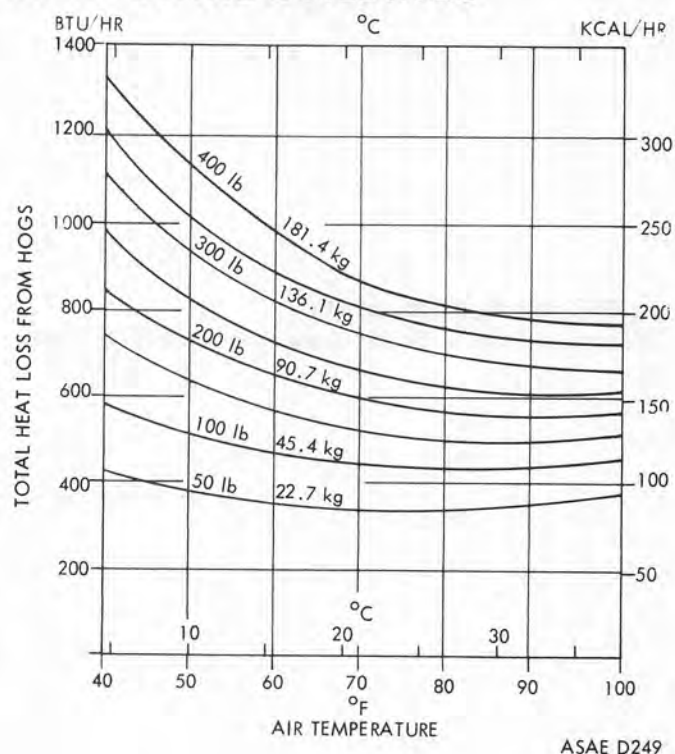


Fig 221-1. Total heat loss of swine.

Air velocity 20-30 ft/min (10-15 cm/sec); 50% RH; room, wall and air temperatures the same. (Bond, Kelly and Heitman, 1959)

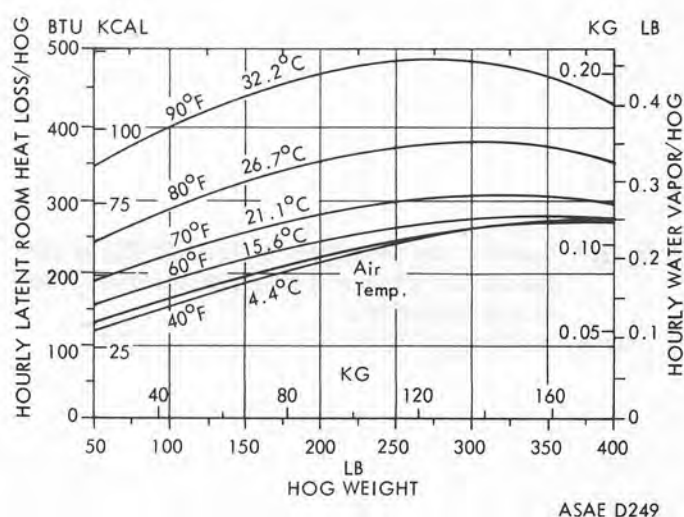


Fig 221-2. Room latent heat in a hog house with solid concrete floor scraped daily.

No bedding, air velocity 20-30 ft/min (10-15 cm/sec), and RH about 50%. (Bond, Kelly and Heitman, 1959)

Water vapor from a fully slotted-floor house is 0.42 as much from a solid-floor house. For partially slotted house, moisture removed is in proportion to the % of floor that is slotted. If bedding is used on solid floor, increase chart values by up to 1/3. (Harmon, Dale and Jones, 1966)

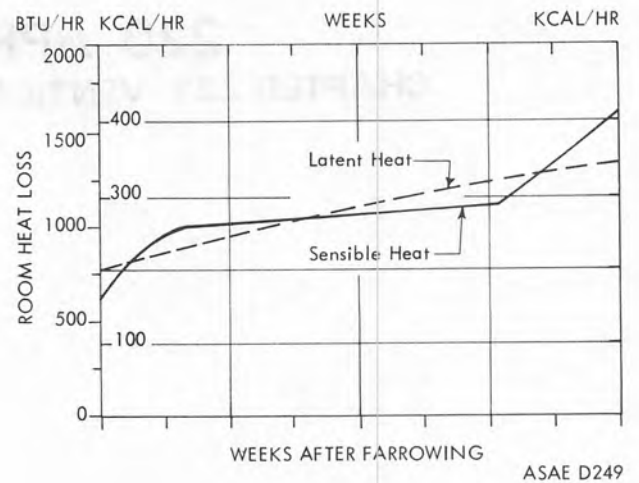
Table 221-1. Partitioned swine heat loss.

Air velocity 35 ft/min (17.8 cm/sec). (Bond, Kelly and Heitman, 1959)

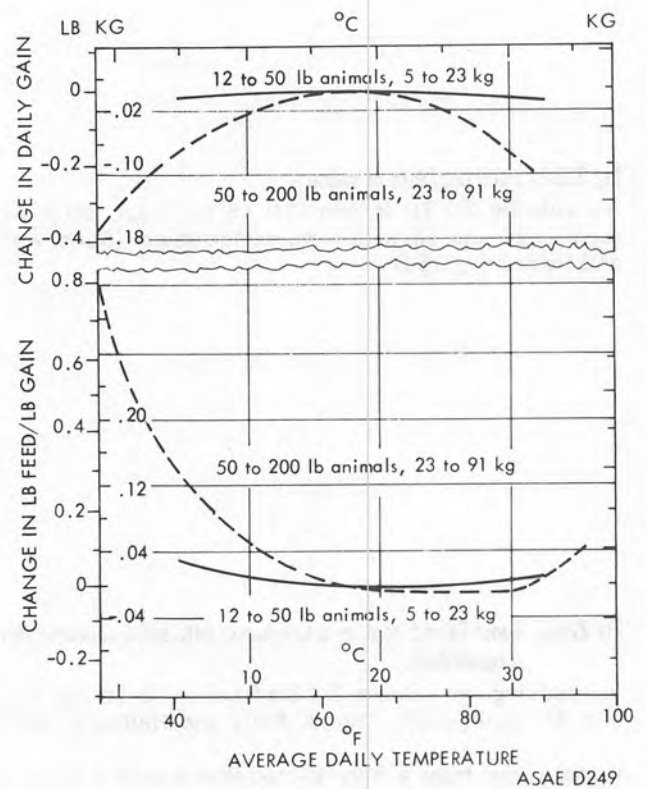
Air Temperature*	deg F	deg C	Percent Heat Loss By:			
			Radiation	Convection	Conduction	Evaporation
40	4.4		34.9	37.8	12.8	14.5
50	10.0		33.0	38.7	12.8	15.5
60	15.6		32.9	38.7	11.8	16.6
70	21.1		27.0	34.3	10.7	28.4
80	26.7		23.0	32.0	7.7	37.3
90	32.2		17.2	20.7	7.4	54.7
100	37.8		2.6	5.0	2.8	89.6

Fig 221-3. Heat loss of a sow and litter.

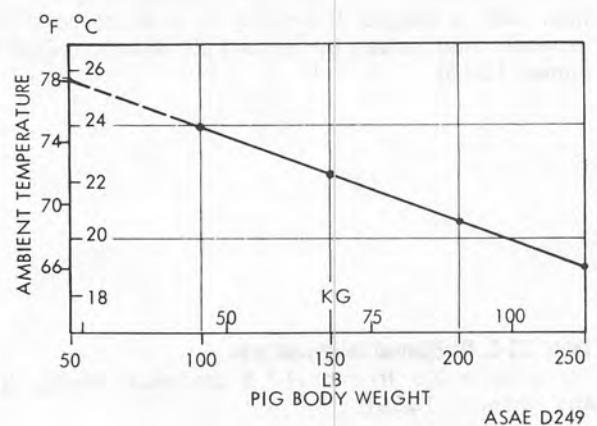
RH about 50%. (Bond, Kelly and Heitman, 1952)

**Fig 221-4. Deviation from performance at 60°F (15.6°C) in daily gain and feed efficiency of swine exposed to various average daily temperatures.**

(Hazen and Mangold, 1960)

**Fig 221-5. Constant ambient temperatures (50% RH) for maximum growth of swine.**

(Heitman, Kelly and Bond, 1958)



FANS

Speed

Ventilation air requirements vary from the minimum winter capacity to many times this value for summer. Fan capacity must adjust to temperature variations to meet changing ventilation needs.

A single-speed fan with an interval timer allows a wide range of capacities, but requires manual setting of the timer for each adjustment. A 1,000 cfm fan on 3 minutes and off 7 minutes provides an average air flow of 300 cfm, but may cause relatively rapid temperature changes. Provide anti-backdraft curtains on inlets if fans are on timers.

Two or more single-speed fans provide a range of capacities.

Newer variable-speed fans modulate air flow from a minimum of about 20% capacity. A solid-state control regulates the voltage going to the capacitor-start, capacitor-run motor. If the solid-state fan control is set at 60°, the fan operates at full capacity when the temperature reaches 64°-65° and drops to minimum capacity at 55°-56°.

Capacity

Select fans rated by an association such as the Air Moving and Conditioning Association (AMCA). For ventilating swine buildings, select the capacity listed at 1/8" or 1/10" static pressure.

Table 221-2 Recommended fan capacities (at 1/8" static pressure).

	Animal Weight lbs	Ventilation Rates, cfm		
		Winter		Summer
		Minimum (continuous)	Normal	
Sow + litter				
Growing pigs	2-20 lb	20 cfm	80 cfm	210 cfm
	20-40 lb	2 cfm	15 cfm	36 cfm
	40-100	5	20	48
	100-150	7	25	72
	150-210	10	35	100
Gilt, sow, or boar				
	200-250 lb	10 cfm	35 cfm	120 cfm
	250-300	12	40	180
	300-500	15	45	250

"Minimum" Winter: Operate at least one fan at all times the inside temperature is above 35°F. Set a thermostat to shut the fan off when the inside temperature drops below 35°F. This fan should supply the cfm rate listed under "Minimum" in the table.

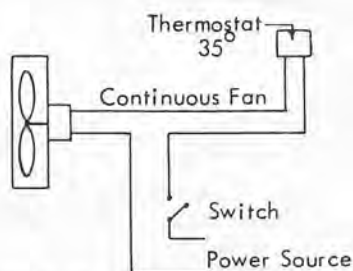


Fig 221-6. Winter fan diagram.

Install this fan to exhaust the air from above any stored liquid manure.

"Normal" Winter: Provide additional fans, thermostatically set to start in 5° steps to prevent sudden drops in temperature. These fans, together with the minimum fans, provide the "normal" capacity for outdoor temperatures up to about 55°F.

Summer: Provide additional fans to supply the cfm rates listed under "Summer" in Table 251-2 OR, install large panels in the walls that can be opened for natural ventilation. Some or all of these fans or panels should be operated when the inside building temperature is above 75°F.

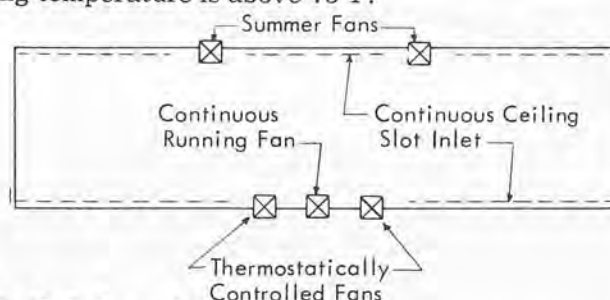


Fig 221-7. Summer fan location.

Circulation fans improve air distribution in winter to aid in drying or heating corners. In summer, they improve animal comfort by increasing air velocity over the skin. Circulation fans can be 1750 rpm unrated units, but should have sealed motors. Provide one 10"-12" swivel-mounted fan for each 50'-60' of wall.

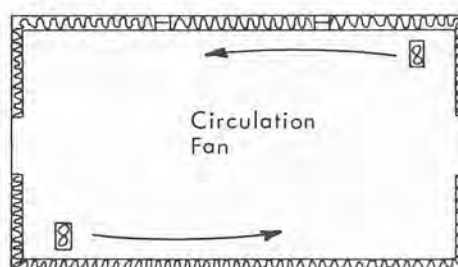


Fig 221-8. Circulation fans.

HEATING

Supplemental heat is added to swine buildings to maintain inside temperature within the range of animal comfort, and to aid in moisture removal and humidity control. As cold outside air is warmed its capacity to absorb water increases, so ventilation air tends to dry out the building. In livestock buildings water is introduced from animal wastes, spilled water, and wash water. Animals also add heat from their bodies, but often not enough for good ventilation.

Enough heat is added to warm outside air to the desired inside temperature and also to evaporate water to be exhausted as vapor. Table 221-3 lists supplemental heat needed for the cold and mild temperature zones of Fig 214-7. Total heat needed = number of litters or animals times the heat required for each.

Table 221-3. Supplemental heat required.

Animal	Inside Temp °F ¹	² Supplemental Heat Btu/hr			
		Slotted Floors		Bedded or Scraped Floors	
		Cold	Mild	Cold	Mild
Sow + Litter	60° ³ 80° ⁴	1500	1000	2000	1400
20-40#	70°	275	125	300	150
		(plus brooder heat for pigs)			
Over 40#	60° ±15°	250	100	500	200

¹Optimum air temperature. Avoid cold air drafts, especially on young pigs.

²See Climate Zone Map

³Solid floors; provide brooder heat.

⁴Slotted floors.

Oil- and gas-fired heaters use air to support combustion. Fumes from the firebox should not be released indoors, but should be ducted directly outdoors. Room air enters the bottom, passes through the fire box, and is exhausted through a chimney. Air is drawn by the fan from the room and/or outdoors, it is heated by passing through heated tubes in the fire box, and is then discharged to the room.

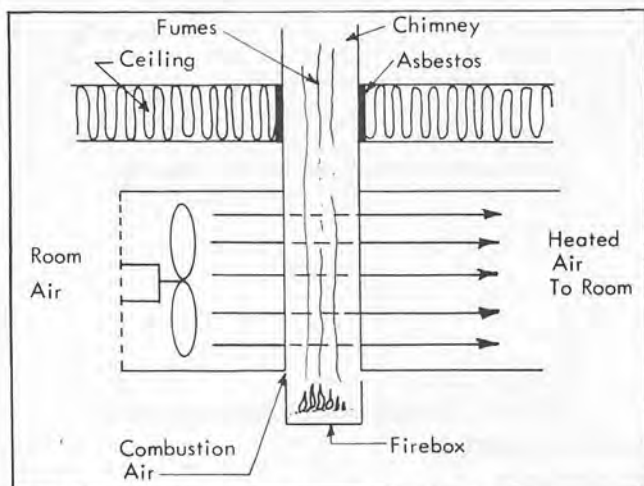


Fig 221-9. Schematic diagram of indirect-fired heater.

Brooder Lamps

Electric heat lamps are commonly used for brooder heat. For nursing areas in cold buildings, 250-watt lamps are recommended. In cold nursing pen or creep areas, 150-watt bulbs are sufficient, and during mild weather 40-watts. Provide 20-amp branch circuits in new construction; limit the number of outlets for both new or in-place wiring to the number of lamps shown in Table 221-4.

Heat lamps are a potential fire hazard. Suspend them on chains; if a lamp becomes unplugged or the wire breaks, the lamp will not fall into bedding. The lamp cord should be 1' shorter than the floor-

to-ceiling height. Mount lamps at least 30" above a pen, or 18" above a creep area.

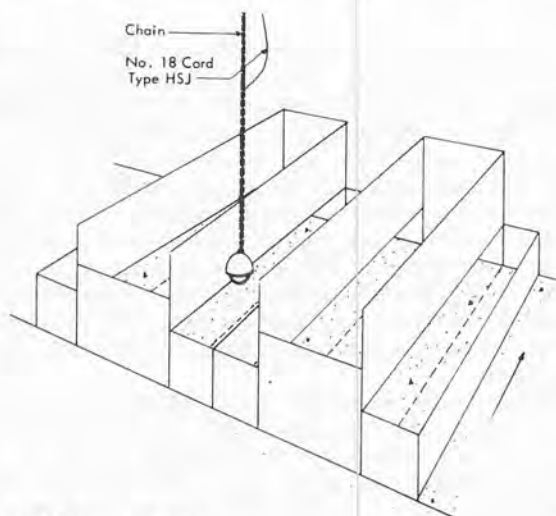


Fig 221-10. Brooder lamp.

Table 221-4. Brooder lamp wiring.

Electrical Load	Meter to Hoghouse	No. & Size of Wire in Air*
Up to 6 Brooders and Lighting 1750 Watts	Up to 50 ft 50 to 150 ft 150 to 250 ft	2 - #10 2 - #8 2 - #6
Up to 13 Brooders and Lighting 3500 Watts	Up to 50 ft 50 to 150 ft 150 to 250 ft	3 - #10 3 - #8 3 - #6
Up to 25 Brooders and Lighting 8000 Watts	Up to 70 ft 70 to 100 ft 100 to 175 ft	3 - #8 3 - #6 3 - #4

*Use next larger wire size for underground installation.

Wire size—building circuits (115V)

Wire Size ¹	Capacity ² Amps.	Max. No. Brooder Lamps	
		150w	250w
14	15	9	5
12	20	12	7

¹No. 12 wire minimum recommended size for all new appliance circuits.

²1750 watts maximum load per circuit (check state code).

Underfloor Hot Air Heat

Warm air can be distributed with an underfloor system. The laterals provide some floor heating in the creep area. Turn the outlets to blow air toward the sows in summer, toward the pigs in winter.

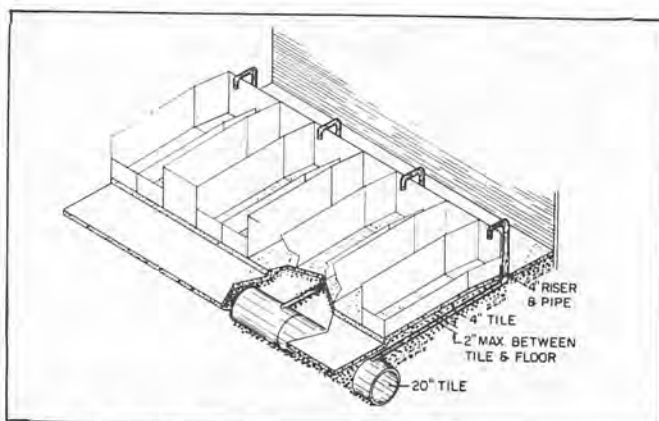


Fig 221-11. Hot air floor heat.

Electric Cable

Install a snap switch for each coil except in coils where the thermostat is located. Electrically ground all steel stalls and waterers. Do not place cable directly on plastic insulation.

Electric cable usually has a lower installation cost than piping, avoids freezing problems, and permits individual pen control.

Table 221-5. Electric heat cable spacing.

The cable is labeled with the watts per linear foot. This table gives the spacing, in inches between wires to obtain the desired watts/sq ft.

Watts per square foot	Watts per linear foot of heating cable				
	2-1/2	2-3/4	3-1/2	5	7-1/2
	(Spacing between adjacent runs of cable, inches)				
25	1-3/16	1-5/16	1-11/16	2-3/8	3-5/8
30	1	1-1/8	1-3/8	2	3
35	—	—	1-3/16	1-3/4	2-9/16
40	—	—	1-1/16	1-1/2	2-1/4
45	—	—	—	1-5/16	2
50	—	—	—	1-3/16	1-13/16
55	—	—	—	1-1/8	1-5/8
60	—	—	—	1	1-1/2

Underfloor Cable or Pipe Heat

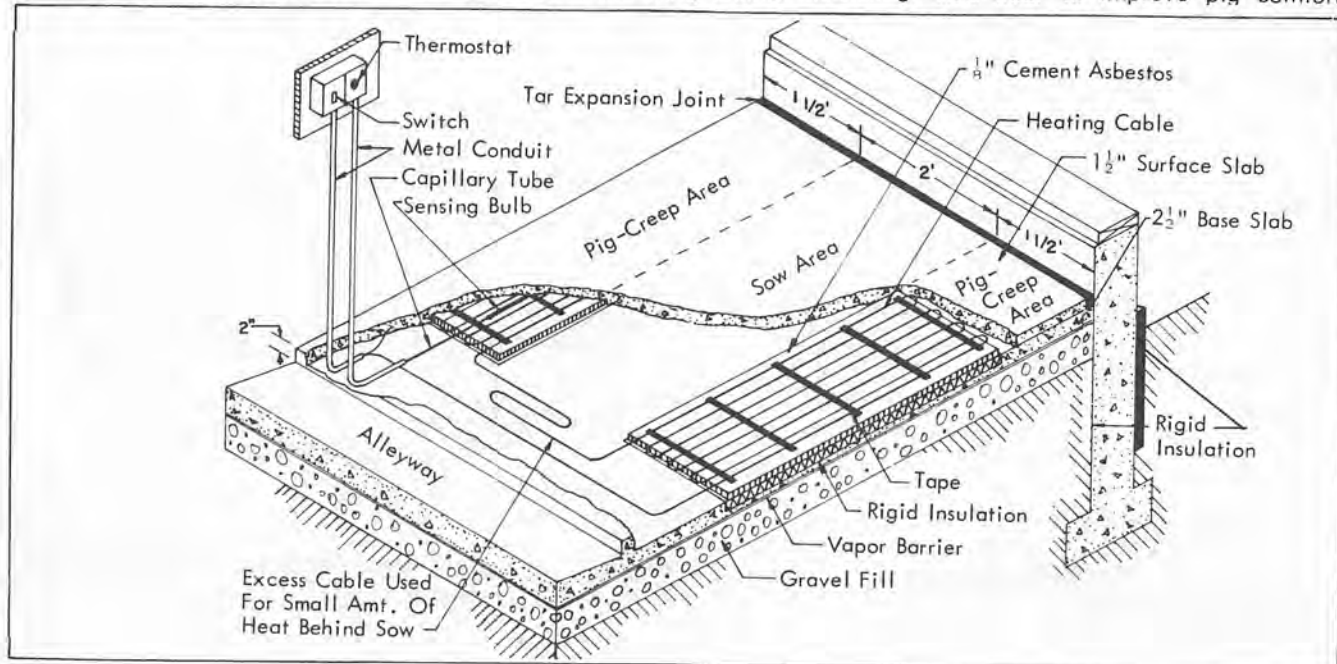
Floor heat provides a warm dry floor for young pigs. Little or no bedding is used. Heat lamps commonly supplement the floor heat for 2-3 days during cold weather farrowing. Install perimeter insulation when stalls are placed near the outside walls.

Use approximately 85°-90° slab temperature at farrowing. Lower gradually to 70° when pigs are 3 weeks old. Discontinue floor heat at 4 to 5 weeks of age. Gradually adjust air temperature until conditions during the last few days in the growing pens are equal to conditions in finishing unit.

Install a thermostat with a cross-ambient fill sensing bulb on 5' of capillary tube. Install a 1" copper pipe 2" deep and 2" from a heating element so that one end extends into the heated area of the floor in the desired location for the sensing bulb. Insert the sensing bulb in the pipe. To calibrate the thermostat (which indicates internal instead of surface slab temperature), adjust it to obtain desired surface temperatures measured with a thermometer laid on the floor.

Install sufficient cable to supply 30 to 40 watts per square foot of creep area for baby pigs and about 25 watts per square foot of sleeping area for weaned pigs (35 watts if open-front building). Imbed the cable 1-1/2" into the concrete and space uniformly. The cable will burn out if two wires touch or cross. Use cable approved for use in concrete. Install one thermostat for each 4 or 5 pens.

Fig 221-12. Electric floor heat. Electric cable is buried in the creep area of farrowing stall floor to improve pig comfort.



Hot Water

Hot water heating will usually have lower operating costs than electric cable.

Install 3/4" copper, wrought iron, black iron, or high temperature plastic pipe. Do not use galvanized iron or cold water plastic pipe. Place the pipe to within 6" of the edge of a concrete slab and 2" from the top. Space the pipes about 12" apart.

Provide adequate water heating and circulating equipment. An input of 50 Btu/hour for each foot of pipe should keep the floor temperature at 80°F. Feet of pipe times 50 Btu/hr = the output required from the boiler or water heater. A 30-gallon gas water heater supplies about 24,000 Btu/hour. Heat water to about 140°F.

A simplified piping layout for farrowing stalls and typical plumbing equipment is illustrated below.

- Heat source: gas hot water heater (up to about 60,000 Btu/hr) or commercial boiler.
- Water supply valve: water is in a closed system so little water is added. The valve is used to close down the system.
- Relief valve: releases water when pressure gets too high; locate so pigs and people will not get burned.

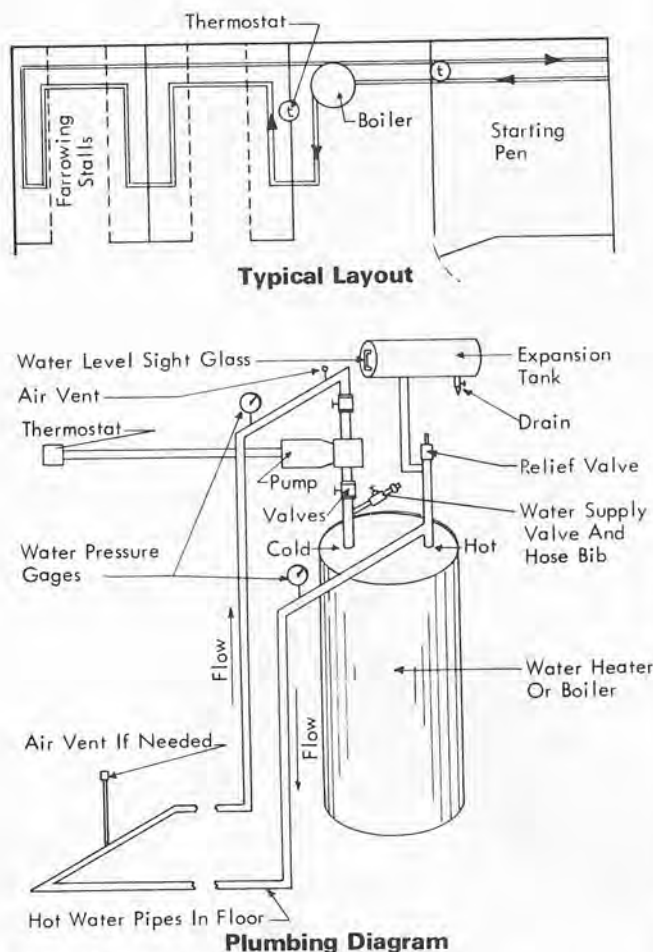


Fig 221-13. Hot water floor heat.

- Expansion tank: an air tank to allow for the expansion of water as it is heated. A sight glass permits checking water level; the level in the expansion tank should be low when the system is cold.
- Pump: circulating type, installed in the return line. Capacity: 1 gallon per minute for each 10,000 Btu/hour in a growing or finishing unit, and about 5000 Btu/hour in farrowing or nursery units.
- Air vent to drain air out of the pipes. Provide one at the pump and one at any high spot in the hot or return lines.
- Water gauges to indicate when system needs service. Note the pressure difference when the system is new and operating properly. A decrease in the difference indicates a worn pump or air blockage. An increase indicates a blockage—sediment, or a partially closed valve.
- Thermostat with remote sensing bulb in the floor to control pump operation.

Contact a local heating contractor for assistance in installing a hot water floor heating system.

COOLING

Evaporative Cooling

When air passes through a wet pad it evaporates moisture, gives up heat, and is cooled. The air temperature is lowered, but the relative humidity is increased.

Evaporative cooling is most effective in the dry Southwest. In this area, evaporative cooling is relief cooling, reducing room temperatures to about 20°F below outdoors. Although not down to optimum temperatures, the reduction is significant.

In areas of higher relative humidities, cooling is less effective. But even in the central corn belt, an evaporative cooler can reduce air temperatures about 8°F. During the hottest part of the day, humidities are apt to be at their lowest. And, the large fans required are helpful in milder weather.

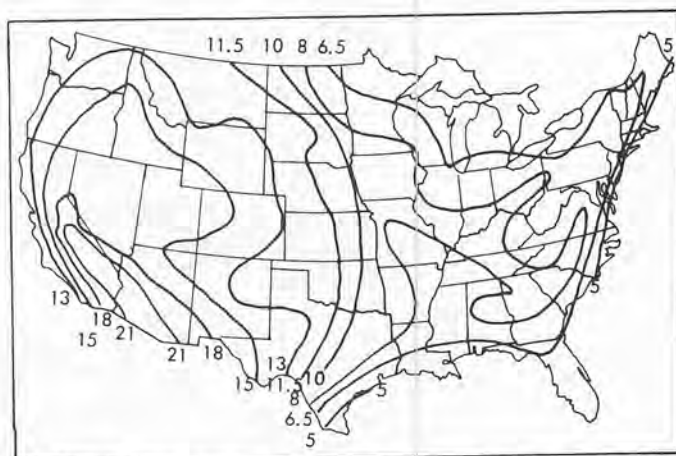


Fig 221-14. Average room temperature drop from maximum outdoor July temperature.

Mechanical Cooling

Mechanical air conditioning equipment has found limited use in swine production buildings. One effective system for farrowing houses uses a small blower.

Spray Cooling

Pigs can keep cool at high temperatures through evaporation of moisture from their bodies. Wet down your pigs with a spray nozzle system and intermittent spraying.

About 0.09 gallons of water per hour per pig is sufficient, or a spray capacity of 0.045 gpm per pig. If one nozzle is used in each pen:

Table 221-6. Water required for spray cooling.

Pigs/Pen	Nozzle size (gpm)
10	0.45
20	0.90
30	1.35

Select a nozzle to cover at least 3/4 the width of the pen with a solid cone of droplets—not a mist or fog. Nozzle design (spray angle and pattern) and mounting height affect the sprayed area at pig height.

Give your dealer your water analysis so he can help you select the proper nozzle. Corrosive water or water with a high hardness content can cause problems. You may need a noncorrosive nozzle that is easy to clean.

Locate the spray nozzle over the manure collection area of the pen.

Place a cleanable in-line filter and solenoid valve in the waterline between the water source and the spray line.

Install a timer between the electricity source and a thermostat. Set the timer for 2 minutes on in a 60-minute cycle. Set the thermostat at 75°.

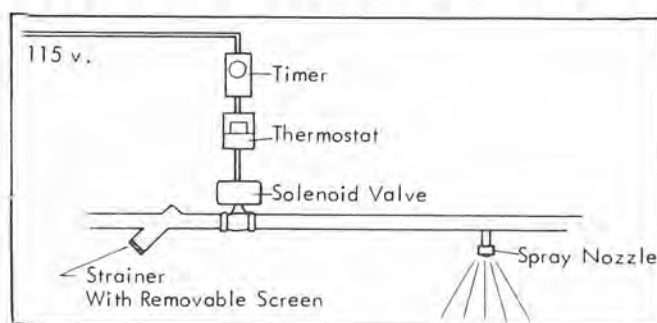


Fig 221-15. Diagram of spray cooling system.

Blower Specification: Fans for use in a duct are commonly rated at 0" and 1/2" static pressure, rather than the 1/8" usually specified for blade fans. Use squirrel-cage blowers rated at 70 cfm or more at 0" and at least 50 cfm at 1/2"; each blower will draw about 0.7 amps.

Summer: Operate one blower per occupied stall full time, with thermostat set to turn units off at 60°F. Turn deflectors to blow toward the sows.

Fall: As outside temperatures drop, unplug and cap enough of the blowers so those remaining connected run almost continuously during daytime. Turn deflectors to blow toward the ceiling.

Winter: During cold weather, have one out of 4 or 5 of the blowers operating almost continuously during daytime. Set the thermostat at 35°.

Air Intake: Air may be drawn from the attic during winter months. Draw air directly from the outside during warm and hot weather. Have no more than 8 blowers on a single run from an intake, or enlarge duct proportionately.

Air Outlets: Provide screened (1/2" hardware cloth) hooded openings, about 1 sq ft free area per 10 blowers, in south wall. Or, provide ceiling vents with insulated ducts to ridge ventilators. These ducts can be disconnected during summer so the exhaust air ventilates the attic.

Cooling: A window air conditioner, 1/10 ton per sow, can be added to the unit for summer cooling.

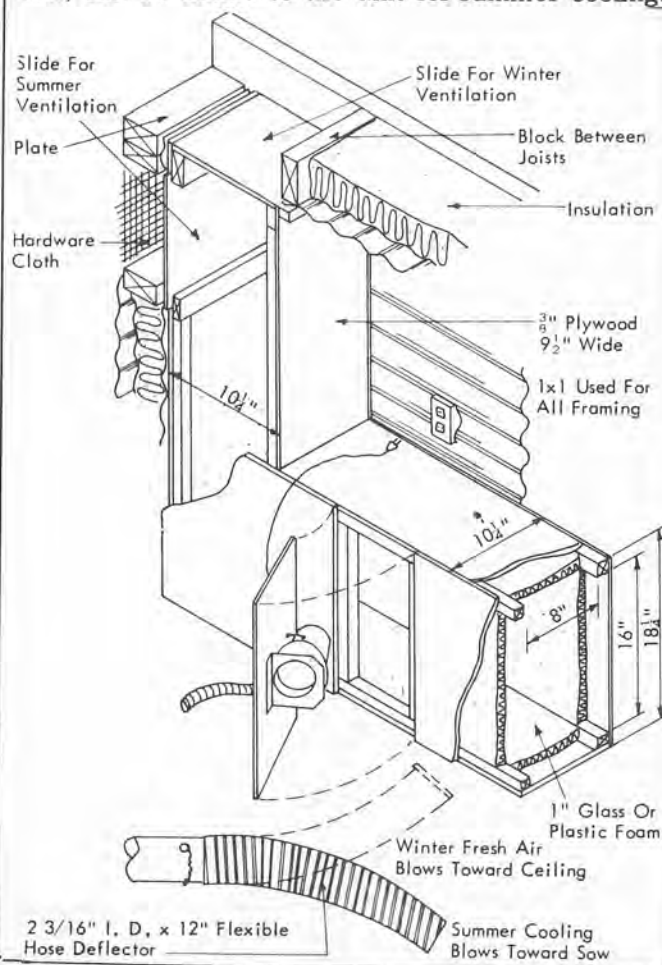


Fig 221-16. Individual blower.

CHAPTER 222 VENTILATION OF BEEF BUILDINGS

Warm Confinement

The building is designed to use fans to provide air movement, at least in the winter. Insulation and a vapor barrier are required. Supplemental heat will be required to maintain condensation control at temperatures below about 10°F if indoor conditions are to be maintained above 35°F.

Summer ventilation may be provided by fans or by opening about 1/2 of all wall area for natural ventilation.

Table 222-1. Recommended ventilation rates, cfm. (All climate areas, per 1000# animal).

Minimum Winter	15 cfm continuous. Draw air from pits if manure is stored under slotted floors.
Fall and Spring	100 cfm. With more than 1 fan, start fans at 50, 55, 60, etc. °F to avoid sudden temperature changes.
Summer	200 cfm minimum + pit fans.

Cold Confinement

See Chapter 215.

Table 222-2. Recommended insulation and supplemental heat.
(See temperature zone map)

	Climate Area		
	Mild	Moderate	Cold
Insulation (R)			
Ceiling	12	16	23
Walls	9	9-14	14
Insulation, approx (R = 3.5/inch)			
Ceiling	3"	4"	6"
Walls	2"	2"-3½"	3½"
Supplemental Heat, btu/hr (approx per 1000# animal)		400	900

CHAPTER 223 VENTILATION OF DAIRY BUILDINGS

What are optimum conditions for dairy cows? Research at the University of Missouri Psychro-energetic Laboratory has indicated no change in production for Holsteins at 10°-70°F with a decline in production above 75°F. Jersey cows showed no change between 30°F and 80°F with declines above and below these temperatures.

Most controlled environment dairy buildings are kept at 40°-60°F from November through April. Relative humidities of from 60%-80% are common in ventilated dairy buildings.

Heat

Heat the milking room, milkroom, toilet, and utility room to prevent freezing in the coldest weather. Provide supplemental heat, if necessary, to maintain a 50° temperature during milking and milkroom operations. Heat from the cooler compressor, water heater, and separate heaters or furnaces can be used. Equipment heat should be exhausted in warm weather.

Heat supplied by cooling milk can be utilized to heat the milking parlor and/or milkhouse. Cooling 100 pounds of milk from 98° to 40°F supplies about 4,800 Btu of heat—about the same as a 2KW electric heater running for 1 hour. A system to utilize this heat can be built into most facilities at very little extra cost. Put the compressor, vacuum pump, water heater and furnace in one utility room. Connect the furnace blower to come on when the compressor starts. Connect the furnace to a thermostat in the milking parlor (or milkroom) so when milk heat is insufficient the furnace will come on. An insulated door to the outside can be opened in summer so the compressor heat will be blown outside.

Ventilation

Ventilate the milkroom with a 1000 cfm intake fan to assure that air is not drawn from the milking room. Locate the fan so air is drawn in from the cleanest and most dust-free side of the building.

Air outlets can be in the utility room, toilet room, and the wall opposite the fan.

Ventilate the milking room with an exhaust fan, with inlets in the wall on the opposite side of the building, or from the attic.

Air outlets and inlets should be screened and have a total area of one square foot per 700 cfm fan capacity. Size fans in both the milkroom and milking room to move 6 air changes (6 times room volume) per hour in winter.

For summer ventilation, use fans of 12 or more air changes per hour capacity, or screened windows, or both. Attics should be vented with screened louvers and/or eave vents.

FANS

Fan Capacity

The following are the approximate requirements for fan selection:

Table 223-1. Fan capacity, cubic feet per minute (cfm), based on 100cfm/1000 lb body weight.

	Cow	Calf	Yearling
Jersey	100 cfm	35 cfm	50 cfm
Guernsey	110	35	50
Ayrshire	115	38	55
Brown Swiss	140	45	70
Holstein	150	50	75

During extremely cold weather, about one-fourth the above capacity should run continuously. At temperatures between the season's low and high, varying amounts of air are needed. To provide this range, select one fan with one-fourth the capacity to run continuously and control the other fan or fans with a thermostat.

Example: 60 Brown Swiss at 140 cfm = 8400 cfm

Select one fan at $\frac{1}{4}$ x 8400 or	2000 cfm
Select two fans at 3200 each or	6400
Total	8400 cfm

Warm Barn

A warm barn is usually preferred for more than 10-15 calves. Maintain temperatures between 40° and 50°F. Walls should have insulating value, R, of 10 to 12. Ceilings should have insulating value, R, of 18 to 20.

Calf area should be partitioned off from milking herd so adequate conditions can be maintained for the small animals. In a warm barn calves can be tied in individual stalls to reduce floor area per animal. Automatic waterers can be provided.

Provide ventilation for winter of 1/10 cfm/lb of calf.

Supplemental Heat for Calf Barns

To maintain the desirable inside temperature of about 50°F in a calf barn, more heat is needed than the animals can provide. (Do not simply shut down ventilation fans, as poor humidity conditions and condensation will result.)

To estimate the amount of supplemental heat needed in a well insulated building:

Multiply:
 weight of calves, lb x 4 = _____
 wall area, sq ft x 5 = _____
 glass area, sq ft x 10 = _____
 Total (add) _____

The total is the number of Btu's (British thermal units) of heat to be provided by electric or vented gas or oil heaters. Divide Btu's needed by 3000 to obtain kilowatt rating of electric heater.

Set the heater thermostat to shut the heater off about 5°F below the temperature the main winter fans (usually 55°F) turn on.

Note: Calf pen areas in stanchion barns can be difficult to keep ventilated and dry. In cold climates, locate pen area to the east or south end of the barn.

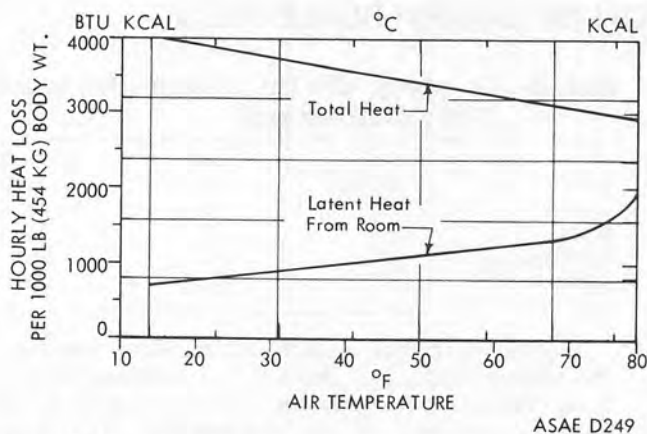


Fig 223-1. Barn heat and moisture loss of stanchioned dairy cattle. RH = 55-70%.

Total barn heat declined rapidly above 80°F (26.7°C) (Yeck and Stewart, 1959)

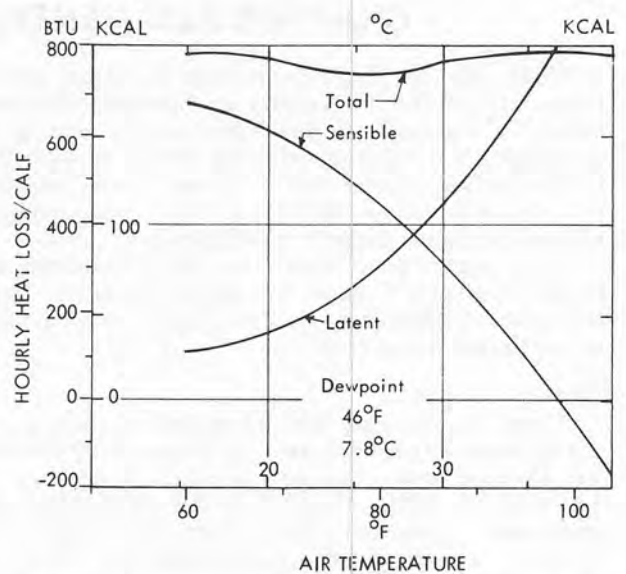


Fig 223-2. Milk yield vs. air temperature, cows at constant temperature, RH about 50%. (Johnson, 1965)

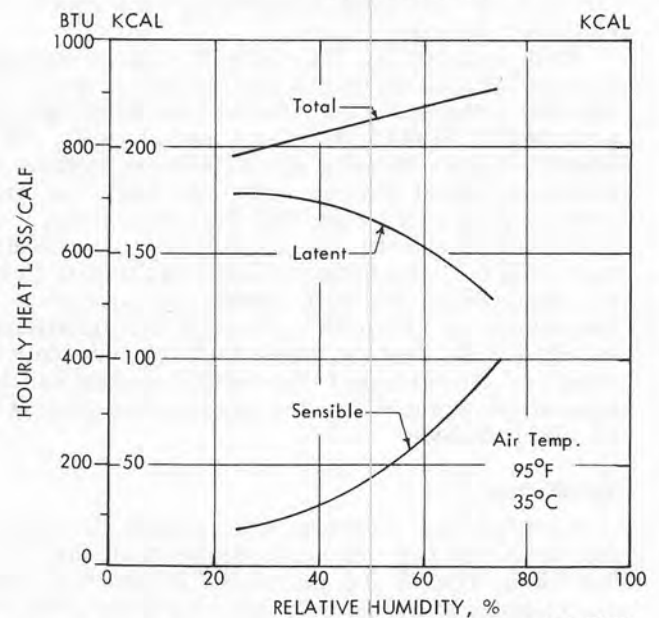


Fig 223-3. Heat loss of 3 Ayrshire bull calves, 6 to 10 months old. Vapor pressure 8 mm Hg. (McLean, 1963)

CHAPTER 224 VENTILATION OF SHEEP BUILDINGS

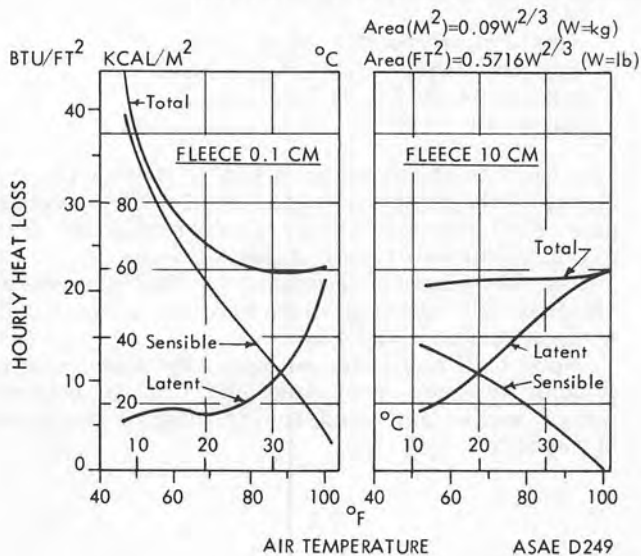


Fig 224-1. Heat loss of sheep (half bred x Dover-Cross wethers). RH 45-54%.

Air flow: 4 ft³/min or 4 cfm (1.9 liters/sec). (Blaxter, McC. Graham and Wainman, 1959)

CHAPTER 225 VENTILATION OF HORSE BUILDINGS

As a rule, horse owners in mild or moderate climates can obtain adequate housing for their animals with uninsulated buildings. However, wood or masonry sidewalls and tight sheathing under the roof are desirable.

In northern regions, insulated buildings and supplemental heat are more commonly used to protect the animals and attendants from severe winter weather. Heated barns are also used for show horses to keep them in show condition throughout the year.

Enclosed buildings are usually tightly constructed with snug-fitting doors and windows. They may be uninsulated or insulated. Uninsulated and some insulated barns are used for cold housing. Only well-insulated buildings can be used for warm housing. As the move is made from cold to warm housing, the ventilation system requires more refinements.

SUPPLEMENTAL HEAT

Heat must be supplied to warm housing to control moisture and maintain indoor temperatures above freezing when outside temperatures fall below about 15°F. The usual source of heat in a warm barn is the animals. Horses normally produce 200 to 300 Btu (British thermal units) per hour for each 100 lb of animal weight.

The design of most warm animal barns is based on an animal density of 15 to 40 lb/sq ft of total floor space in the barn. The density in a horse barn with two rows of 12' x 12' box stalls and a 12' center alley is as low as 2 lb/sq ft. Because of this low density, more heat is needed than the horses can provide. Consequently, the insulation requirement for a warm horse barn is greater than for other mature animals, and supplemental heat has to be supplied.

Stopping the ventilation fans to raise the temperature in the barn increases humidity, condensation, and odors—the barn becomes clammy and smelly.

If the amount of insulation recommended in Table 214-1, and the ventilation rates shown in Table 215-4, are used for an all-stall barn, the approximate amount of supplemental heat needed for different conditions can be determined by adding the "building heat loss" and the "ventilation heat loss" for the selected minimum inside winter temperature. This simplified procedure assumes that animal heat is sufficient to control moisture. Additional heat will be needed if higher ventilation rates are used.

The "building heat loss" (Btu/hr) is determined by multiplying the inside wall and ceiling areas (sq ft) by the indicated multiplier for the zone and adding the results. Table 225-1.

The "ventilation heat loss" (Btu/hr) is determined by multiplying the weight of the animals by the multiplier for the appropriate climate zone. Ventilation heat loss will increase about another 10% for each 5 cfm increase in ventilation rates above those recommended.

Computing Supplemental Heat

Building Heat Loss (Btu/hr)

Select the ceiling and wall multipliers from Table 225-1 for your desired inside conditions and your climate area (map, Fig 214-7).

Building heat loss = ceiling area (sq ft) x Ceiling multiplier + wall area (sq ft) x Wall multiplier

Example: 36' x 36' barn with 5 box stalls is to be kept at 45°-50°F in Indiana.

Ceiling area = 36' x 36' = 1296 sq ft

Ceiling multiplier (mild zone) = 4.2

Wall area = 4 walls x 8' high x 36' long = 1152 sq ft

Wall multiplier (mild zone) = 5.5

Building Heat Loss = 4.2 x 1296 + 5.5 x 1152 = 5443 + 6336 = 11,779 Btu/hr.

Table 225-1. Heat loss multipliers.

	35°F inside			45°-50°F inside		
	cold	moderate	mild	cold	moderate	mild
Ceiling	2.4	2.8	2.9	3.0	3.7	4.2
Wall	3.9	3.8	3.9	5.0	5.0	5.5
Ventilation	3.0	2.4	1.9	3.9	3.2	2.7

Ventilation Heat Loss

Select the ventilation multiplier for your inside temperature and climate zone.

Ventilation Heat Loss = Weight of horses (lb) x multiplier

Example: Assume 5, 1000 lb horses in the barn of the example above.

Ventilation Heat Loss = 5 x 1000 lb x 2.7 = 13,500 Btu/hr

Total Heat Loss = Building Loss + Ventilation Loss

Example: Supplemental Heat needed = Total Heat Loss = 11,799 + 13,500 = 25,299 Btu/hr

NOTE: When figuring areas (sq ft) and the roof is the ceiling, treat the roof area as the ceiling area and the ends of the building as part of the total wall area.

Install heating equipment according to the manufacturers' recommendations.

IMPORTANT: Heaters using gas, liquid, or solid fuel must be vented to the outside by means of a fire-safe chimney or flue, to carry the by-products of combustion out of the building.

Set the thermostat to shut the heater off below the temperature at which the main winter fans start to operate (usually 50°-55°F).

CHAPTER 226 VENTILATION OF POULTRY BUILDINGS

Laying Hens

Air Temperature: 45°F min, 85°F max

Daily Temperature fluctuation:

±5° between 45° and 65°

±10° between 65° and 85°

Over 85°F, maximum night cooling

Relative Humidity: 50%-75%

Ventilation

A minimum of 1/4 cfm per bird is required when the outside temperature is below 20°F. 1 cfm per pound live weight should be provided continuously above 70°F.

A fan capacity of 5 cfm per bird (maximum 1000 birds per fan) is required. Ventilation openings should be 1 1/2 sq ft per 1000 cfm fan capacity. Louvers in the attic, as in the slot inlet system, should have 1 1/2 sq ft free area per 1000 cfm.

Heat and Moisture per 1000 Hens

Moisture produced in dropping and respiration:

28 lb per hr @ 80°F

22 lb " @ 55°F

19 " @ 30°F

Plus 3-4 lbs per hr water spilled. Heat production:

37,500 BTU per hr @ 80°F

50,000 " @ 55°F

58,000 " @ 30°F

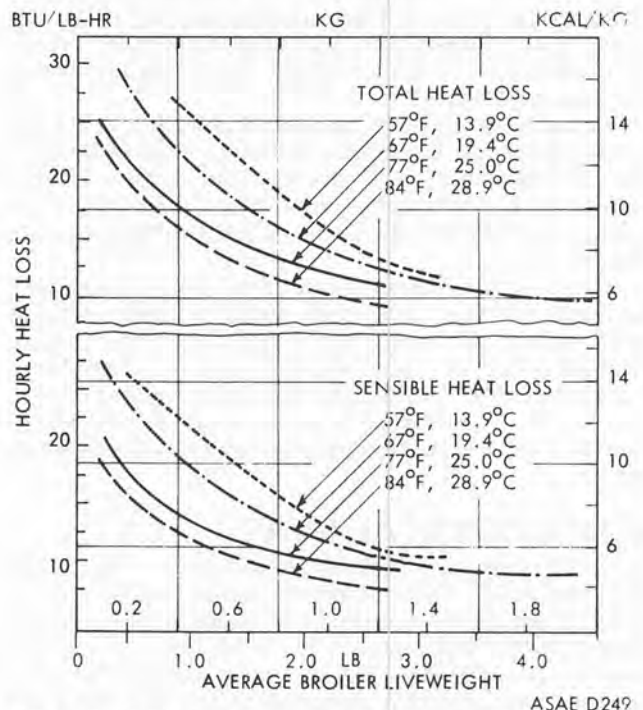
Insulation Recommendations

Walls

R value of 8-10 (frame wall + 1"-2" insulation, or 8" lightweight concrete block + 2" insulation + interior lining). The walls should be peck proof.

Ceiling

R value of 12-15 (lining + 4" fill insulation).



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Fig 226-2. Heat loss of growing broilers at 75% relative humidity. (Ota and McNally, 1966)

Table 226-1. Hourly moisture production of 1000 4 lb (1.8 kg) white leghorn laying hens.

(Ota, 1966)

Temperature		Respired		Defecated		Total*	
deg F	deg C	lb	kg	lb	kg	lb	kg
25	-3.9	6.3	2.9	14.5	6.6	22.8	10.4
35	1.7	8.3	3.8	14.5	6.6	24.8	11.3
45	7.2	8.4	3.8	12.9	5.9	23.7	10.8
60	15.6	11.4	5.2	12.7	5.8	26.4	12.0
80	26.7	14.3	6.5	14.4	6.4	31.6	14.3
95	35.0	20.0	9.1	10.3	4.7	33.7	15.3

*Includes wasted drinking water estimated at 10% of water consumed from 25°-80°F (-3.9° to 36.7°C) and 15% at 95°F (35.0°C)

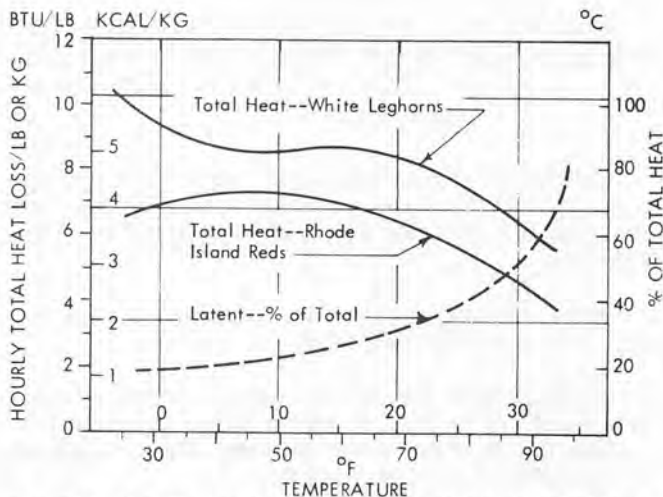


Fig 226-1. Total and latent heat losses of Rhode Island red and white leghorn laying hens. (Ota and McNally, 1961)

230 FRUIT AND VEGETABLES STORAGE

CHAPTER 231 CONTROLLED ATMOSPHERE FRUIT STORAGE*

The principal characteristic of controlled atmosphere storage is a modification of the atmosphere in the storage room. The atmosphere normally contains 20%-21% oxygen, 0.03% carbon dioxide, traces of inert gases, and the balance nitrogen. Apples can be stored for prolonged periods in atmospheres of 3%-5% oxygen and 0%-5% carbon dioxide, with the balance nitrogen. The term "modified atmosphere" is sometimes used rather than "controlled atmosphere" or CA, the term used here. Regular storage is the conventional refrigerated storage now used by most growers.

While all the effects of atmospheric modification on apples are not known, there is a reduction in the rates of the chemical reactions that normally occur in fruits stored in normal atmospheres at comparable temperatures. With CA, desirable quality is maintained over longer storage periods. The effects usually can be observed only after about 90 days; therefore, place part of the crop in regular storage for use during the first 90 to 125 days after harvest, and the remainder in CA for later use.

Storage Scald Control

CA storage greatly increases the susceptibility of apples to a storage or superficial scald, but it can be effectively controlled with scald inhibitors. Apples in CA must be treated. Scald control materials and methods are described in West Virginia Agricultural Experiment Station Current Report 47. Treatment of regular stored fruit, while not essential, is recommended.

Atmosphere Modification and Control

Product generated atmosphere (Conventional CA)

As apple fruits respire they absorb oxygen from the surrounding atmosphere and produce carbon dioxide. If the fruit is in a gas-tight room, the oxygen level lowers and carbon dioxide accumulates. Fruit respiration modifies the atmosphere in about two weeks. Since there are critical levels for apples, some oxygen is added to the room periodically, and excess carbon dioxide is removed. The period of oxygen concentration reduction is termed the "pull-down."

To maintain proper atmosphere, determine the oxygen and carbon dioxide concentrations, usually with an Orsat gas analyzer. The volume of a gas sample is measured, and the oxygen and carbon dioxide are removed by chemical absorbers. The decreased sample volume measures the oxygen and carbon dioxide originally present. Analyze the atmospheres at least once a day.

Carbon Dioxide Scrubbers. Excess carbon dioxide can be removed from the storage in several ways.

Caustic Soda Scrubber. Although the first CA rooms used sodium hydroxide, or caustic soda, it is not used extensively now because it is very corrosive and difficult to handle. Pumps and plumbing

must be replaced often. Spray mist will injure fruit.

Water Scrubbers. Water (or brine) can also remove enough carbon dioxide. Water or brine to defrost evaporator coils also absorbs carbon dioxide. This water is circulated through an aeration system to remove the absorbed carbon dioxide.

One of the most common aerators is the so-called "stovepipe." Water is pumped from the collecting pan underneath the evaporator coils, taken outside the storage room, and sprayed into a length of 6"-12" stovepipe. As water falls through the pipe, carbon dioxide is released. The water is collected in a sump and pumped back over the evaporator coils. For a 12,000-bushel room, about 70 gpm of water are circulated.

For rooms with dry evaporator coils, blow air through a closed chamber into which the water or brine is sprayed. Again, the water is aerated to remove the absorbed carbon dioxide.

Generally, water or brine alone cannot remove all excess carbon dioxide during the pull-down. Caustic soda may be used for 2-4 weeks after the room is sealed. The caustic soda is then replaced with water or brine.

An alternate to caustic soda is fresh hydrated, high-calcium spray lime. It is placed in the room where air is circulated over it. The lime also may be in a small "lime room." About 0.10-0.15 lb lime per bushel of fruit is recommended. If the lime is packaged in paper bags without plastic film liners, it is not necessary to open the bags.

Externally generated atmospheres

Generators outside the storage rooms produce a gas mixture with a low oxygen concentration, and, if desired, a relatively high carbon dioxide concentration. This modification burns air and propane or natural gas with a catalyst. Undesirable impurities are removed with scrubbers. A water-cooled exchanger removes the heat of combustion. The gas is flushed through the room continuously or only during pull-down.

After pull-down, circulation may be continuous or intermittent. The atmosphere is passed through a carbon dioxide absorber only when the concentration is too high. A fresh air intake provides oxygen when its concentration is too low. Systems that recirculate the atmosphere allow the fruit to do much of the work of maintaining the modified atmosphere. Continuous flushing provides a guaranteed constant atmosphere but requires a large amount of fuel and electricity.

For externally generated atmospheres, the pull-down is less than 5 days as compared with 7-14 days for product-generated CA. Rooms supplied with an externally generated atmosphere may not have to be as gas tight as with product generation; however, "leaky" rooms are more expensive to operate. The cost of properly sealing a room can be easily recovered in lower operating costs. With externally generated atmospheres, the room can

*From Selders and Ingle, West Virginia, 1967

be opened, partially emptied, and resealed; conventional CA rooms cannot be resealed. Operating a room only partially full is more expensive. Rather than opening and closing large rooms, consider smaller rooms to be emptied in a month or so.

Liquid nitrogen can flush conventional CA rooms and hasten pull-down. Liquid nitrogen also has a refrigerating effect to accelerate cooling. No major equipment investments are required to use nitrogen. Nitrogen generators can flush conventional rooms; these are relatively small units that can be on pallets or skids and moved as successive rooms are filled.

Precautions. CA storages do not have enough oxygen to support human breathing. To enter a room for repairs during storage, wear breathing supporting equipment. Have at least one person outside the room for each one in the room. Oxygen deficiency results in momentary collapse.

When the room is opened, remove fruit when gas analyses show 18-20% oxygen concentration or enter for a very short time until there is sufficient oxygen present.

Construction of CA Storages

Structural requirements for foundations, floor, wall, roof, and other parts are the same as for regular refrigerated storage rooms. There is one additional requirement—a good gas seal extending completely around the room, including the floor and ceiling.

Room Size. There is probably no "best" size for CA rooms; they range from 1000 boxes to 50,000 boxes. The size of a room depends partly on the rate at which the room can be filled and the rate the fruit can be marketed once the room is opened. Some states have laws specifying time limits for filling the room, the atmosphere established, and that the apples must be left in the controlled atmosphere for a certain period (usually 90 days), before they can be marketed as CA apples.

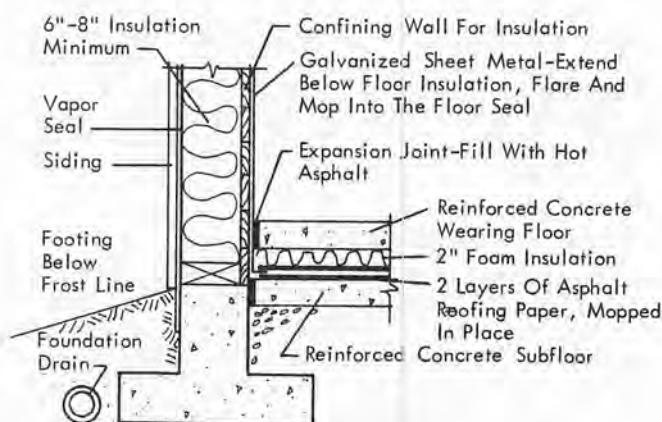
Another factor is the number of varieties of apples stored. Because of varietal responses to different atmospheres and temperatures, it is recommended that certain varieties not be stored in the same room. If 5 or 6 varieties are to be in CA, provide at least two rooms.

Insulation. In general, insulation is the same for CA rooms as for conventional refrigerated storages. Provide an adequate gas seal in CA rooms. Some foam-type insulations applied with proper mastics and coatings provide both a vapor barrier and gas seal.

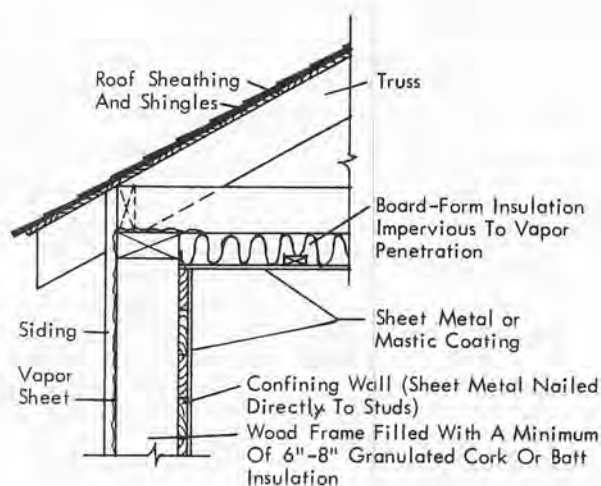
Wood Frame Structures. Wood frame structures for CA rooms are usually stud construction with the vapor barrier and siding on the outside, and a 28-gauge sheet metal gas seal on the inner surface. Fill the wall space with granulated cork, bat, or other insulation. Nail metal lining to either the lumber wall used to confine the insulation, or to the studs or other nailing strips to serve as the confining wall. Wall framing is rigid—any movement in the wall can break the gas seal. In gable roof construction, the sheet metal is under the ceiling and insulation is above it.

Aluminum corrodes from the salt brine spray from refrigeration units. Apply protective coatings to the aluminum, particularly near the cooling unit.

Seal nail holes and metal joints with a high-grade gun caulking that will not dry out. Lap metal sheets about 2"; lay caulking under the sheet before nailing. Then lay another bead on top of the first sheet and fasten the second sheet with large-headed galvanized nails spaced 2"-3". Caulking that oozes out is smoothed over the overlap and all nail heads. Leave 1/8"-1/4" between butted sheets. Caulk under the sheets before they are fastened. Then a metal moulding is slightly overfilled with caulking and is fastened with screws every 6"-8".



**Wood Frame
Floor-Wall Juncture**



**Wood Frame
Ceiling-Wall Juncture**

Fig 231-1. Construction details for CA storage.

Floors. Pour concrete sub-floor on sand or gravel fill. Two layers of 55 lb asphalt-impregnated roofing paper are mopped in hot asphalt and applied over the subfloor for a good gas seal. Stagger joints. Or, 2 or 3 layers of roofer's felt are made into a typical built-up roof over the subfloor. Tie the wall seal to the floor seal. Wall metal can be flared 12"-18" out on the floor and hot-mopped into the felt or roofing paper. Coat any metal in contact with concrete with hot asphalt to check corrosion. Apply rigid insulation strong enough to support floor loads over the gas seal. Floor insulation may not be used, but most engineers recommend at least 2" of floor insulation for CA rooms. Two in. or more of perimeter insulation extending 1'-2' below the floor is recommended if the floor is not insulated. With single wall construction the perimeter insulation can be a continuation of the wall insulation. Provide perimeter insulation for double wall construction by extending the double wall 12" below the bottom of the floor.

Pour a reinforced concrete wearing slab, at least 5" thick, over the insulation to carry the loads imposed on the floor. A 3/4" space is left between the concrete slab and the wall and filled with hot asphalt to make an expansion joint and to ensure a good seal.

Doors. Make doors for CA rooms large enough for a fork lift truck—about 6'-8' wide by 8'-10' high. Plan the layout to have only one door per room if possible. Doors for CA rooms must be gas tight. Sealing around the door is as important as sealing walls, floor, and ceiling.

Steel-clad insulated doors or closure panels bolted to the walls from the inside are used in CA rooms. Seal doors with heavy galvanized sheet metal bolted to the inside of the door opening. The metal door is uninsulated and a standard hinged cooler door is used on the outside. Provide a second opening for a man to crawl through with a 6"-8" porthole for removing fruit samples and for observation.

Testing for Gastightness. Test CA rooms for gastightness before storing fruit, preferably in the morning and with about equal indoor and outdoor temperatures. Leave one man in the storage with a ladder or scaffolding and gun-grade caulking. He will be able to hear most leaks. Blow air into the storage to a pressure below 1-1/2" water. Read air pressure loss on a tilted manometer draft gauge sensitive to 0.1" pressure. Small storages must be tighter than large ones; pressure should not drop to zero in less than an hour for a 2000 bu room, or less than 1/2 hour in a 10,000 bu room. A gastight room continues to lose pressure over several hours.

CHAPTER 232 POTATO STORAGE *

Storage Management

A properly constructed and managed potato storage provides adequate cooling, discourages rot organism development, retards sprout growth, and reduces dehydration and excessive moisture loss.

Storage management involves three periods: wound healing and curing, storage and holding, and removal or grading.

Initial storage conditions provide for suberization, which is rapid healing (curing) of skinned, bruised, or cut potatoes to prevent entry of disease through injured areas. For disease-free potatoes, the recommended temperature is about 60°F and the relative humidity over 90% for the curing period. These conditions are often achieved during the first 7-10 days of storage by restricting the ventilation. Maintain 60°F and 90% during the curing period of about seven days.

If diseases such as late blight or field frost are present, lower the storage temperature rapidly to below 50°F, even though curing is slower at the lower temperature.

Desirable storage temperature depends on potato use:

- Store potatoes for seed and fresh use at about 40°F.
- Store at 45°F for dried or flaked potatoes.
- Store at 45°-50°F for french fries.
- Maintain 50°-55°F for potatoes for chips.

Temperatures should be maintained with $\pm 2^\circ\text{F}$, particularly for process potatoes.

Tubers can be kept for only 12-15 weeks at 50°F before they begin to sprout, but at 40°F they can be kept up to 40 weeks without chemical sprout inhibitors. Long-term storage without excessive shrinkage or sprouting requires a temperature close to 40°F and relative humidities of 85%-95%. The higher temperatures needed to reduce sugar formation in processing potatoes also encourage sprouting, so chemical sprout inhibitors are used. Chemical inhibitors are also used on potatoes for fresh use after more than 8-9 months storage. Refrigeration usually is needed for storage into warm weather.

Relative humidities above 90% may cause unavoidable condensation even on well insulated walls and ceilings. Below 85% R.H. the potatoes shrink and lose weight rapidly. Limit shrinkage to less than 1% per month. Check storage temperatures in different locations, relative humidities, and equipment operation daily.

Operate ventilation fans at full capacity during cool-down following curing and if potatoes start going out of condition in storage. At other times, run the fans at reduced volume. Don't trust automatic

controls completely; they are not foolproof. Dampers can freeze in place in cold weather, heaters can go out, and other equipment can fail.

Long bins may require a temporary booster fan at the ceiling about $\frac{3}{4}$ of the way back from the exhaust stack to help circulate air back to the stack. Use high volume, low pressure basket-type fans. Ventilation systems need to be adjusted and balanced occasionally to meet changing storage requirements.

Remove the tubers from storage carefully regardless of the method used. Cold brittle potatoes injure easily. Warming them to 45°F or above before taking them from the storage reduces cullage over 2%. Restricted ventilation permits respiration heat to raise the temperature.

Building Requirements

Most new storages are built above ground for efficient handling. The storage must be properly insulated to control condensation and heat loss. Insulate outside walls to R25 and ceilings to R35.

Because the storage will be warmer than outdoors in winter and colder than outdoors in summer, good vapor barriers must be provided on both faces of the walls to protect insulation from high moisture conditions. Moisture can greatly reduce the effectiveness of loose fill or batt insulation and can harm the structure. Commonly used vapor barriers are 4 or 6 mil polyethylene sheeting. Tape all seams in the polyethylene and any access holes made for electrical wiring, etc.

Potatoes weigh approximately 42 lb/cubic ft (PCF).

Heat and Moisture Production

The heat produced by potatoes varies with the time in storage and their temperature. Potatoes at 40°F emit 1,100-1,760 Btu/ton-day and at 60°F give off 1,500-2,600 Btu/ton-day. The lower figures are for potatoes that have been in storage several months.

In well insulated storage, very little heat is required to maintain proper temperatures. However, if air is exhausted and fresh air brought into the storage to lower relative humidity, heat may be required to temper incoming air. Five Btu/hr furnace output per 100 lb of potatoes has been found adequate to maintain 45°-55°F. The electrical heat equivalent is 1.5 watts/10.0 lb.

The moisture given off by potatoes depends on temperature, length of time in storage, condition of the tubers, and other factors. Estimate the amount of water vapor produced at 0.5% per month of potato weight.

*Prepared by Darnell R. Lundstrom, Extension Agricultural Engineer, North Dakota State University

A control system maintains temperature and relative humidity levels:

- Potatoes give off enough moisture to maintain humidity. Reduce excess humidity with cool or refrigerated outside air replacing some of the moisture-laden inside air. If the storage becomes cooler than desired, supply additional heat.
- Potatoes give off heat. If the storage becomes too warm when the outdoor air is cool, bring in outside air.
- Recirculate the storage air through the potatoes periodically, whether or not outside air and/or heat are required.
- If outside air is warmer than the desired inside temperature, no air is brought into the storage even though temperature and/or humidity inside are above the desired levels. Or, circulate refrigerated air.
- Install low-temperature limit (35°F) and high-temperature limit (45°-60°F depending on desired temperature) thermostats on ventilation fans to prevent accidental frosting or overheating.

Air Requirements

If the storage temperature increases as little as 2°F, or the humidity exceeds 95%, and the outdoor air temperature is lower than the storage temperature, exchange outside and inside air.

Provide ventilation capacity for 1 cu ft/min (cfm) per 100 lb (0.4 cfm/bu) of potatoes in 40°-45°F storage or 1½ cfm per 100 lb in 45°-55°F storages at ¾" static pressure.

After curing and cool-down, reduce air flow to about half those rates to maintain desired storage

conditions. A two-speed fan, more than one fan, or fans that run intermittently provide variable flow rates.

Most new buildings are designed with a through type of ventilation system. Air is forced up through the pile of potatoes from ducts spaced up to 12' o.c. Provide 1 sq ft of duct area per 1,000 cfm of air. In long bins, a tapered or reduced duct size can be used as the distance from the fan increases and the duct carries less air. Air distribution is usually good if the total area of duct outlets equals the duct cross sectional area. In bulk storage where the potatoes rest against duct openings, the potatoes cover about ¾ of the duct openings; provide openings from the duct equal to four times the duct cross sectional area.

Humidification and Refrigeration

Humidifiers increase or maintain high relative humidities. A humidifier capacity of about 1 gal/hr per 1,000 cfm is usually adequate. The centrifugal atomizer type throws moisture into the air by centrifugal force from a rapidly rotating disc. Water evaporates from the pad type. Place humidifiers in the plenum chamber immediately behind the circulation fan where all air, recirculated or fresh incoming, passes over them. Free water in the duct results from incomplete evaporation. This must be anticipated and provisions made for drainage.

Storages are often refrigerated for seed potatoes and long-term storage of table or processing potatoes. Refrigeration capacity removes heat gain through building surfaces and the heat generated by the potatoes. Capacities of 6 tons of refrigeration per million lb of potatoes have proved satisfactory; more may be necessary in warm climates.

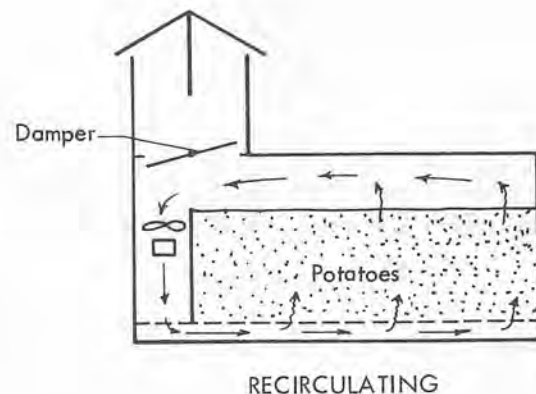
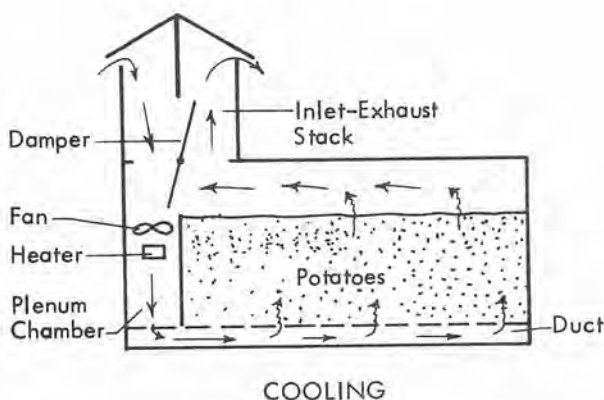


Fig 232-1. A complete "through" potato ventilation system.

Product	Heat of respiration at different temp.		% Water	Normal storage Temp. °F.	Freezing Temp. °F.	Specific heat		Latent heat of fusion
	Temp. °F.	Btu/ton-24 hr.				After freezing	Before freezing	
Apples	32 40 60 85	600-800 1100-1760 4400-6600 6600-15,400	84	31-32	28.4	0.45	0.86	120
Asparagus			93	32	29.8	0.43	0.95	134
Beans, green	40	2,706	89	32-40	30	0.47	0.92	128
Beans, dried			12	40		0.24	0.30	18
Beets	40	1870	88	32-35	27			
Cabbage			92	32	31	0.43	0.93	129
Cantaloupe			93	50-55	29	0.34	0.56	65
Carrots	40	1408	88	32	30	0.45	0.86	120
Cauliflower			92	32	30	0.48	0.94	134
Celery	40	2606	94	31-32	30	0.49	0.96	137
Cherries	32 60	1320-1760 11,000-13,200	83	31-32	28	0.45	0.86	118
Corn, dried			11	45		0.23	0.28	15
Corn, sweet	40	3806	74	31-32	29	0.43	0.80	108
Fruits, dried			30	32-50		0.32	0.47	43
Flour and Meal			20	40		0.28	0.38	29
Grapes								
(Cornuchon, Tokay)	35 60 80	660-1100 2200-2640 5500-6600	82	31-32	27	0.38	0.67	84
(Concord)	35 60 80	1320 6600 15,400						
Lemons	35 60 77 80	440 1760 2200-3300 3300	89	55-58	28	0.39	0.70	90
Lettuce	40	7392	95	32	31	0.48	0.95	135
Nuts				32-70		0.24	0.28	14
Onions	32 50 70	660-1100 1760-1980 3080-4180	88	32	30.0	0.46	0.90	127
Oranges	35 60 80	440 1760 3300	87	34	28	0.39	0.70	90
Parsnips			79	32-34	29	0.45	0.86	120
Peaches	35 60 80	1540-1980 6600-13,200 15,400-22,000	87	31-32	29	0.46	0.90	125
Pears	32 60	660-880 8800-13,200	83	30-32	29	0.45	0.86	120
Peas, dried			10	40		0.22	0.28	14
Peas, fresh			74	32	30	0.42	0.80	108
Peppers	40	1,518	92	32	30			
Plums			86	31-32	28	0.45	0.87	121
Potatoes	32 50 70	660-1100 880-1760 1100-1760 2200-3560	78	36-60	29	0.42	0.78	105
(Irish Cobbler)	40							
Potatoes, sweet	40 85	880-1320 6600-8800	69	50-55	28	0.41	0.75	99
Radishes			92	33		0.48	0.94	132
Raspberries	35 60	4400-6600 15,400-22,000	83	31-32	30			
Strawberries	32 40 60	3300-3740 4840-7700 10,780-14,960	90	31-32	30	0.47	0.92	130
Tomatoes						0.48	0.95	135
(ripe)			94	50-55	30			
(mature green)			95	55-70	30			
Turnips	40	572	91	32	30.5			

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1. Principles of Refrigeration. William H. Motz, Nickerson & Collins Co., Chicago, Ill. Third Edition. 1932.
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300 WASTE MANAGEMENT

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300 WASTE MANAGEMENT

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CHAPTER 311 METHODS OF HANDLING WASTES

Introduction

A complete waste disposal system is no longer a luxury in a livestock business—it is a necessity. Careful waste management is needed to:

- Maintain good animal health through sanitary facilities.
- Avoid pollution of air and water.
- Comply with local, state, and federal regulations.

Animal producers generally have a choice in the method of handling wastes. Wastes are usually handled as a solid from bedded areas or drained solid floors. Semi-liquid wastes come from unbedded floors and some lots. Wastes under slotted floors are usually liquid, as is runoff from lots and manure stacks.

The method of disposal chosen depends greatly on the type of waste being handled. Solids are

usually spread on fields with conventional spreaders. Liquids can be spread on fields with tank wagons, applied with irrigating equipment, or digested in a lagoon before field spreading.

Characteristics of Manure

Manure with up to about 15% solids has liquid handling characteristics. Extra water must often be added to liquefy the manure for handling as a liquid. From 20%-60% of the storage volume may be needed for dilution if the manure is to be pumped. Wastes with up to about 4% solids can be handled with irrigation or flushing equipment. Keep extra water to a minimum if the manure is to be field spread with a tank wagon. Dilute liquid manure can be pumped through irrigation equipment and adds water and fertilizer to crops.

Table 311-1. Daily manure production for size of animal listed.

Table 6-14. Dairy manure production and nutrient content									
Animal Size in pounds		Total Manure Production			Water Density		Nutrient Content		
		lb/day	cu ft/day	gal/day	%	lb/cu ft	N lb/day	P lb/day	K lb/day
		(1)	(2)	(3)	(4)	(5)			
Dairy Cattle	150	12	0.19	1.5	87.3	62	0.06	0.010	0.04
	250	20	0.32	2.4	87.3	62	0.10	0.020	0.07
	500	41	0.66	5.0	87.3	62	0.20	0.036	0.14
	1000	82	1.32	9.9	87.3	62	0.41	0.073	0.27
	1400	115	1.85	13.9	87.3	62	0.57	0.102	0.38
Beef Cattle	500	30	0.50	3.8	88.4	60	0.17	0.056	0.12
	750	45	0.75	5.6	88.4	60	0.26	0.084	0.19
	1000	60	1.0	7.5	88.4	60	0.34	0.11	0.24
	1250	75	1.2	9.4	88.4	60	0.43	0.14	0.31
	cow*	63	1.05	7.9	88.4	60	0.36	0.12	0.26
Swine									
Nursery pig	35	2.3	0.038	0.27	90.8	60	0.016	0.0052	0.010
Growing pig	65	4.2	0.070	0.48	90.8	60	0.029	0.0098	0.020
Finishing pig	150	9.8	0.16	1.13	90.8	60	0.068	0.022	0.045
Gestate sow	275*	8.9	0.15	1.1	90.8	60	0.062	0.021	0.040
Sow & litter	375*	33	0.54	4.0	90.8	60	0.23	0.076	0.15
Boar	350*	11	0.19	1.4	90.8	60	0.078	0.026	0.051
Sheep	100	4.0	0.062	0.46	75	65	0.045	0.0066	0.032
Poultry									
Layers	4	0.21	0.0035	0.027	74.8	60	0.0029	0.0011	0.0012
Broilers	2	0.14	0.0024	0.018	74.8	60	0.0024	0.00054	0.00075
Horse	1000	45	1.5	11	79.1	30	0.27	0.046	0.17

$$(1) \text{ lb/day} = \frac{\text{animal wt}}{1000} \times \text{RM in lb/day-1000 lb}$$

$$(2) \text{ cu ft/day} = \frac{\text{lb/day}}{\text{density}}$$

$$(3) \text{ gal/day} = 7.5 \times \text{cu ft/day}$$

$$(4) \text{ water \%} = 100 - \% \text{RM from Table 2.}$$

$$(5) \text{ density} = \text{best estimate, not ASAE DATA.}$$

*Not ASAE data; assumptions:

cow = 1.05 cu ft/day

gestating sow = 1/2 of ASAE data for her weight because she's limit fed.

sow & litter = ASAE data for her weight + 8 pigs @ 1.0 lb/day.

boar = 1/2 of ASAE data for his weight because he's limit fed.

Table 311.2. Diluting manure with water.

1 cu ft (7.5 gal) Moisture	Changed to Moisture	Cu ft	Gal	Gallons Added
84%	87%	1.23	9.2	1.7
	90	1.60	12.0	4.5
	95	3.10	23.3	15.8
80	85%	1.33	10	2.5
	90	2.0	15	7.5
	95	4.0	30	22.5
75	80%	1.25	9.3	1.8
	85	1.66	12.4	4.9
	90	2.50	18.7	11.2
	95	5.00	37.5	30
70	75%	1.2	9	1.5
	80	1.5	11.3	3.8
	85	2.04	15.2	7.7
	90	3	22.5	15
	95	6	45	37.5

A general range of solids content for manure without bedding is:

- 20-25% solids: stiff, some drying or liquid separation has taken place for most manures.
- 15-20% solids: semi-liquid, quite thick slurry.
- 5-15% solids: liquid slurry.
- 0-5% solids: irrigation or flushing consistency.

Solid Manure Handling

Wastes with 20% or more solids can usually be handled as a solid. Solid manure results from catching and holding excrement in bedding, or by allowing the liquids to run off, leaving the solids to be handled separately.

Handling solid manure requires:

- solid floors that can be bedded or drained.
- a minimum of equipment.
- an area on which to spread the solids.

Suggestions:

- Install sloping floors; locate waterers where manure accumulation is desired; and keep pens full.
- Haul manure directly to fields whenever possible, but avoid spreading on frozen fields.
- When a stockpile is necessary, locate it for convenient loading in a spreader, out of natural drainageways, and away from any water source. Divert surface water away from the storage area.
- Control runoff from stockpiles or lots.

Liquid Manure Handling

Livestock producers handle manure as a liquid for one or more of the following reasons:

- Liquid manure usually requires minimal time and labor, as it can be treated in lagoons or stored in tanks or earth storages until spread.
- Disposal of liquid manure can be postponed to fit field schedules, soil conditions, and expected rainfall, if the storage unit is properly sized.
- Objectionable odors, unsightliness, and fly problems can be controlled when wastes are stored as liquid manure in a covered storage. The odors that occur from spreading are infrequent, but may be more objectionable than those from solid manure.

Handling liquid manure requires the following facilities and equipment:

- Scrapers, gutters, slotted floors, or drains to move the wastes into storage or treatment.
- A storage or treatment unit to which water can be added.
- Pumps, agitators, and augers to stir and remove the liquid manure.
- Tank truck or wagon; irrigation equipment; land to dispose of the manure.
- A lagoon can treat wastes before field spreading.

Some of the confusion about waste disposal systems comes from not understanding what different facilities do.

Gases From Stored Liquid Manure

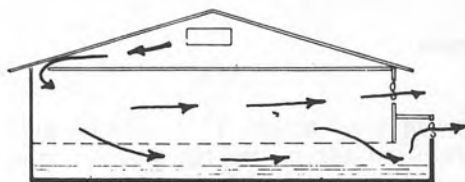
Gases from agitated liquid wastes stored inside a building are hazardous and create undesirable odors. Most gas problems occur when manure is agitated or when ventilation fans fail. Most (99% or more) of the gas is methane, ammonia, hydrogen sulfide, and carbon dioxide.

Animals asphyxiate because methane and carbon dioxide displace oxygen. Ammonia can irritate respiratory tracts and make them more susceptible to disease.

Ventilating manure storages

The primary hazard from manure gases occurs with inadequate ventilation.

Provide maximum building ventilation when agitating or pumping wastes from a pit. Harmful gases can be released in significant amounts; provide plenty of fresh air for workers and animals with open doors and windows, and by operating large fans.



Exhaust some ventilation air from above stored liquids; even a low-volume continuous fan pulling air from above one corner of a tank will aid in reducing the accumulation of gases.

Provide an alarm system (loud bell or readily noticed light) to warn of power failures in totally

enclosed buildings. Tightly closed buildings can have a rapid build-up of gases at animal level that eliminate sufficient oxygen.

Manure gases can kill

Do not enter a storage tank. But if it becomes necessary, have other persons outside the tank with immediate means of removing you in case you inhale dangerous gases. Ventilate the space over the wastes with a large portable fan if possible.

Wear self-contained breathing equipment—fire-fighting or scuba gear. Chemical reaction filter masks are not sufficient. Have one end of a rope secured around your body just below the arms, with the other end secured outside the tank.

Chapter 312 COLLECTING LIVESTOCK WASTES

Introduction

Several collection methods are possible with some handling systems. Some systems combine collection and storage functions, such as a built-up manure pack or slotted floors over a liquid tank. In selecting a collection system, consider:

- Type of facility.
- Labor requirements.
- Investment.
- Total waste handling system.

Slotted Floors

Slotted floors provide rapid separation of an animal from its manure. Size of openings and space between openings depend on the manure's properties and on experience with slipping, foot injury, and other animal response.

Concrete slats are perhaps the most common and durable, but are heaviest and require strongest supports. Wood wears, warps, and is chewed by hogs, leaving irregular slat spacing. Manufactured slotted floor systems of steel, aluminum, and plastic are more uniform than wood or concrete. They may be easier to handle, install, and replace than concrete, but may be more expensive. When selecting slats, consider initial cost, predicted life, intensity of use (wear rate), strength, corrosion, fire, noise, and replacement cost. Slats should be stable; twisting, flexing, or shifting may cause cracks in the slat material or slat coating, or may catch or pinch animals.

Table 312-1. Recommended slat size and spacing

Animal	Slat spacing	
	Narrow slats (1¼"-3")	Wide Slats (4"-8")
BEEF	Not recommended	1½" - 1¾"
DAIRY		
Cows	Not recommended	1½" - 1¾"
Calves	¾" between 1x2's	1¼"
on edge, elevated calf stall		
SWINE		
Farrowing*	¾" (1" behind sow)	¾" or 1"
25 to 40 lb	½"	¾" - 1"
40 to 220 lb	Not recommended	1" - 1¼"
Sows	Not recommended	
SHEEP		
Ewes	1"	1"
Lambs	5/8" - ¾"	¾" - 1"
Feeders	¾" - 1"	1"

*Use 1" slots behind sow, but cover them during farrowing; use ¾" slots elsewhere.

Other Floors

Grates

Grates of steel straps 1"-1½" wide and 3/16-1/4" thick are used for farrowing, nursery pigs, and other small animals. They are spaced 3/8"-3/4" depending on the size of the animal.

Removable steel grates of smooth round rods are best for covering the gutter behind dairy cows in stalls.

Sloping Floors

Sloped floors assist the movement of manure toward gutters or scraped or slotted areas. Animal traffic tends to work manure down slopes of about ½"/ft (4%) or more.

Scrapers and Blades

Scrapers of various types can be used to collect manure. Their main advantage is labor reduction. They are used on solid floors or under slotted floors in gutters, channels, or troughs to move wastes to storage, treatment, or spreading equipment.

Manure freezing during winter in cold confinement buildings can be partly overcome by frequent or continual scraper operation in cold weather. Or, install electric or hot water heat. Heat in sidewalls of deep gutters or pits may be needed to prevent freezing, even if their floors are well below frost. Provide perimeter insulation.

In warm weather, scraping once or twice a day may be satisfactory. More frequent scraping may be necessary to keep animals and animal areas clean, although labor and scraper blade wear increase.

Front-end Loaders

Front-end loaders remove solid manure from open lot surfaces, storages, or building floors. Other farm uses include handling silage, bedding, fertilizer, or other bulk materials.

Conventional agricultural tractor-mounted loaders are available in a variety of styles and sizes. Their turning radius is relatively large, limiting their use to straight runs, or to larger areas where turning is minimal. Avoid building layouts requiring backing down long alleys or working in limited space.

Small self-propelled loaders (skid-steer) can clean in cramped areas, greatly reducing hand labor. Most have a turning radius of their own length and a low height, so can work easily in tight quarters.

Large self-propelled industrial-type loaders can be justified for cleaning extensive open lots, and moving stacked manure where traction is poor. Their main disadvantage is high initial cost.

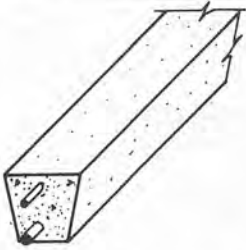


Fig 312-1a. Reinforced concrete.

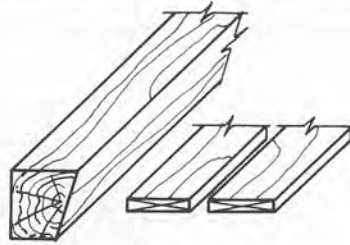


Fig 312-1b. Wood

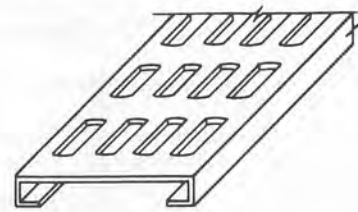


Fig 312-1c. Punched or perforated plastic or steel.

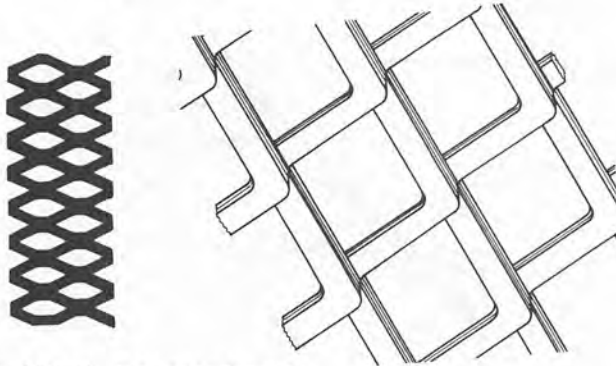


Fig 312-1d. Expanded metal.

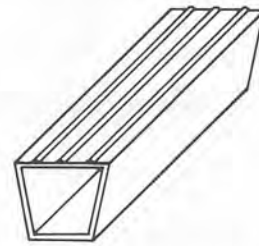


Fig 312-1e. Extruded aluminum, fiberglass or plastic.

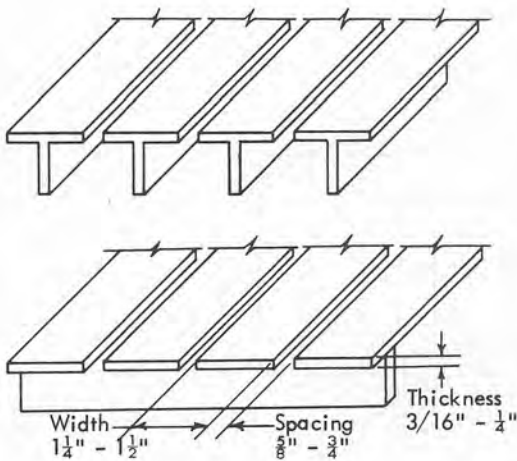


Fig 312-1f. Steel or aluminum bars, straps, or T's.

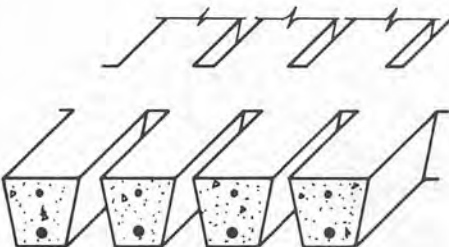


Fig 312-1g. Reinforced concrete gang slat.

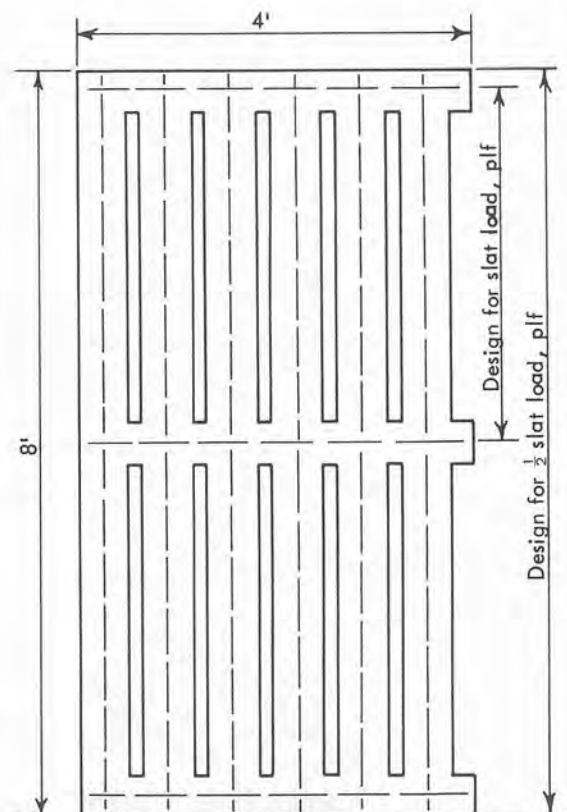


Fig 312-1. Examples of slats.

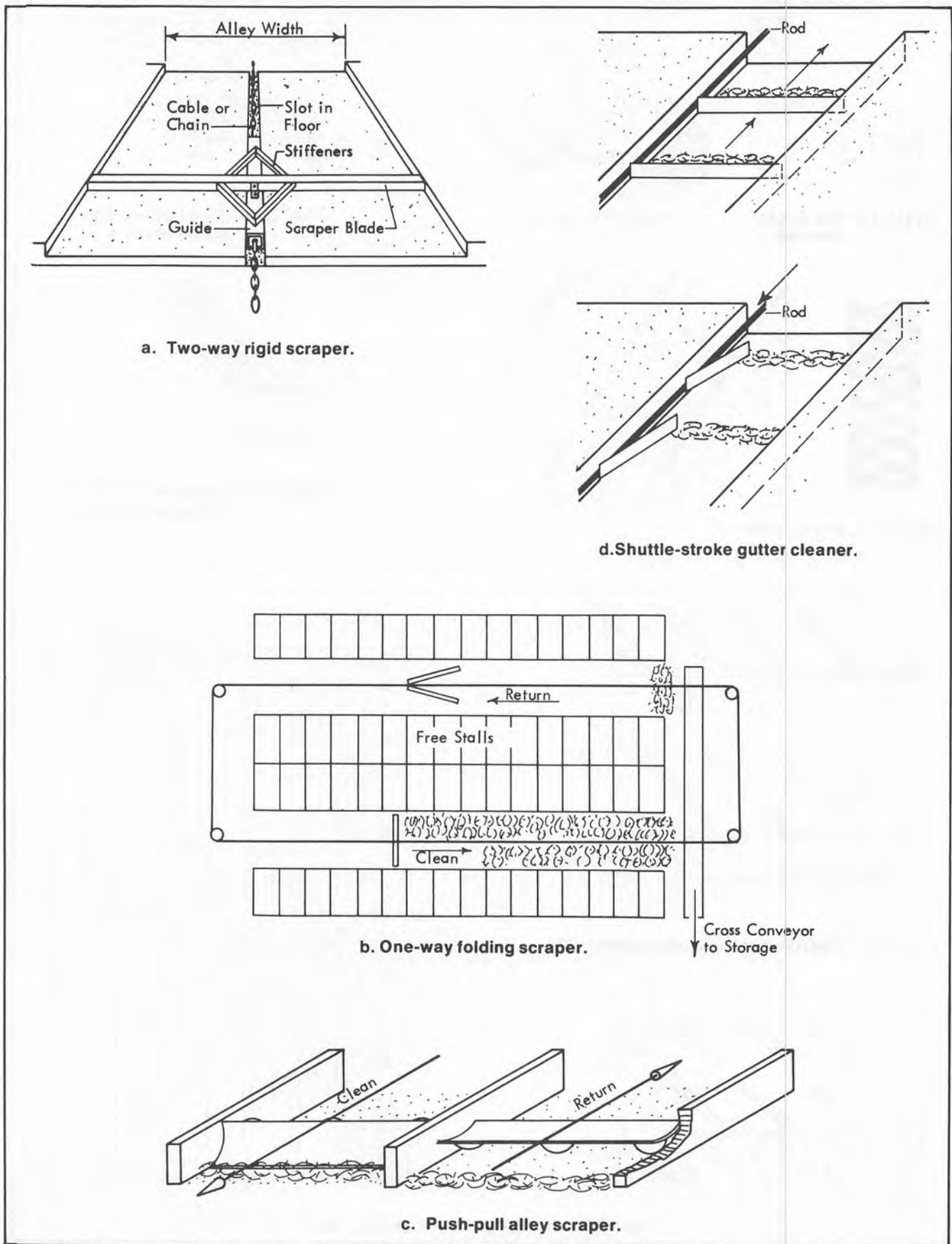


Fig 312-2. Examples of manure scrapers.

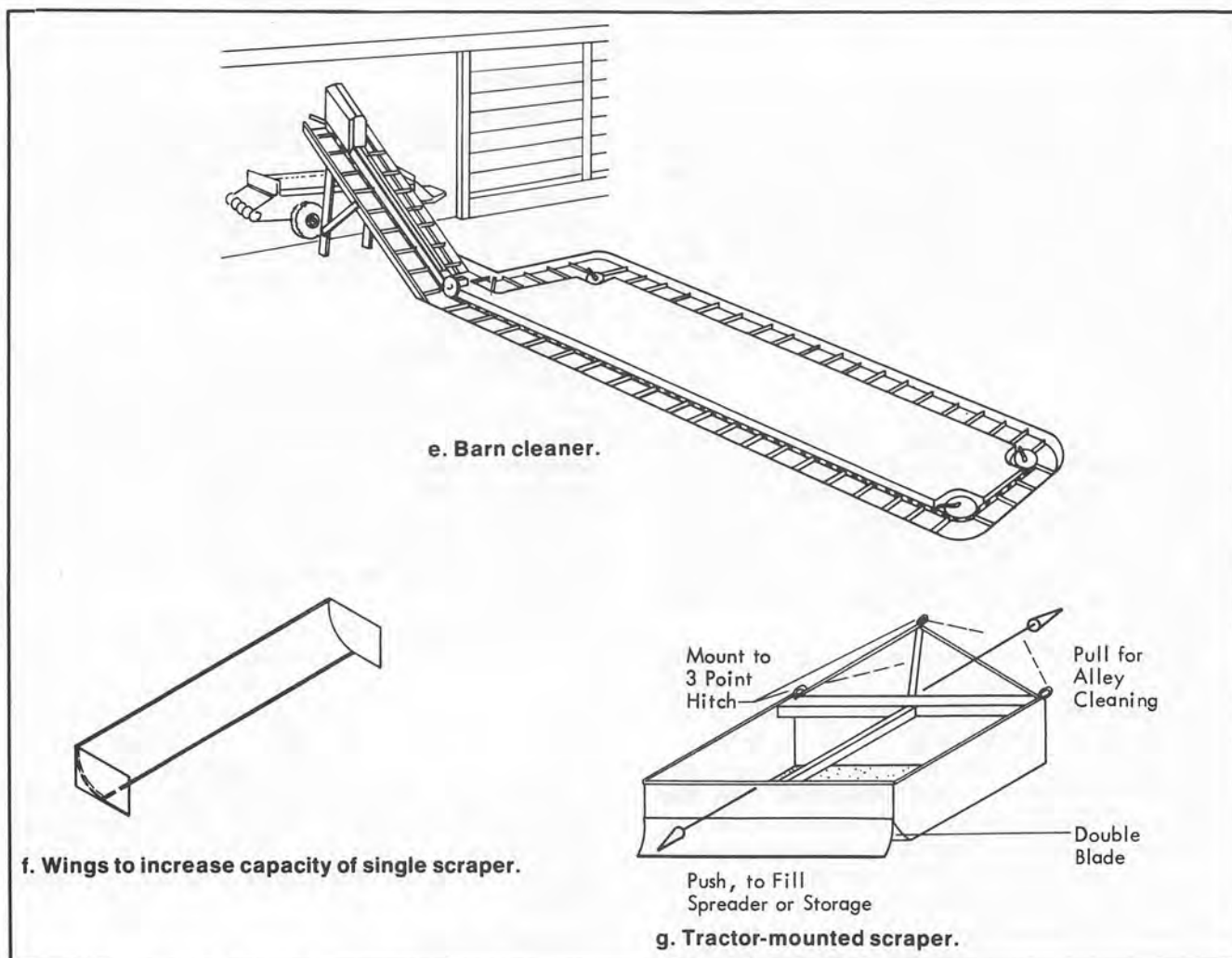


Fig 312-2. Examples of manure scrapers.

Collecting Runoff

A lot includes all outdoor animal areas. **Lot runoff**, whether from rainfall or snowmelt, contains animal manure and is therefore handled in the livestock waste management system.

Runoff from roofs, drives (but not animal alleys), and grassed or cropped areas that does not contain livestock manure is relatively clean. It need not be handled as a livestock waste. **Clean runoff**, although not an accurate description, is a convenient name for runoff that does not contain manure. Clean runoff can be diverted away from the waste management system to reduce the amount of waste volume to be handled, or it can be diverted into the waste system if needed to dilute a lagoon.

Curbs, dikes, and terraces divert water by stopping its flow down a slope. Channels and pipes transport water from one place to another.

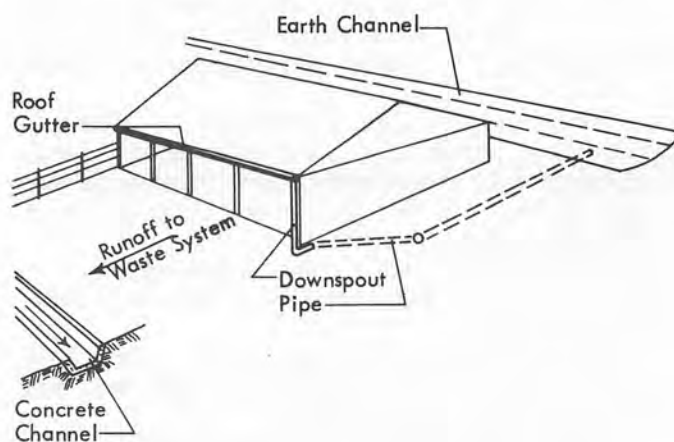


Fig 312-3. Gutters and open channels.

CHAPTER 313 LIVESTOCK WASTE STORAGE

Introduction

The design of livestock housing is often tied closely to selection of a type and size of waste storage. Because of different climates or need for pollution control, requirements or guidelines for the minimum size of waste storages vary between states, as do requirements for location, construction, maintenance, and use. A storage unit may be an outdoor tank, silo, or pond, or part of the livestock facility; that is, a pit under slotted floors or storage gutters.

Location

Avoid locating storages on creviced bed-rock or below the water table, although some soils are so impervious that infiltration is minimal. If shallow bed-rock is present, obtain special review by a qualified engineer or contact your board of health. Also avoid storage in gravel beds or other areas where serious leakage could cause ground water pollution.

Allow at least 100' between a water supply and the nearest part of a storage—check with health authorities. Solid manure storages should be at least 50' from a milkhouse or milking parlor—check with milk authorities. Consider all farmstead operations, other structures, and the farm home. Shield storages from a public road and the family living area. Consider prevailing winds.

Locate, size, and construct storages for use all year, and for field spreading when field, weather, and local regulations permit. Locate and construct storages so they are convenient for filling and emptying and so surface runoff water cannot enter them. Provide all-weather access.

Filling Liquid Manure Storages

Add water to the unit before filling it with manure. Add 3"-4" to pits under slotted floors; add 6"-12" to reduce solids sticking to the pit floor if the unit will be loaded with batches of scraped wastes.

Keep the openings in covered tanks closed when not in use, and maintain a program of fly control, utilizing bait, insecticides, and repellants. Fly reproduction can be discouraged by keeping all solids submerged.

Scrape wastes into a gutter or storage unit frequently to keep them wet. Dry wastes may be difficult to reliquify.

Frozen manure, fibrous material, and debris may interfere with agitation or pumping, and should be kept out of the tank.

Where gases may discharge into a building, provide adequate ventilation. If possible, evacuate the building during agitation prior to cleaning.

Maintenance

Periodic inspection should be made of the tank and its surroundings for leaks, deterioration of grills, covers, and ladders, and adequacy of the roof. Some tanks have covers strong enough to drive on; others have relatively weak covers. A vertical distance from ground to lid of about 18" discourages traffic; maintain this vertical separation.

Storage Capacity

Storage capacity may be regulated and depends on the number and size of animals, amount of dilution by spilled and cleaning water, amount of runoff to be stored, and desired length of time between emptying. Large storage units have the maximum labor advantage. Three to six months' storage capacity is desirable and may be required to avoid spreading where field conditions prohibit—on frozen or snow-covered ground, or on some crops.

$$\text{Storage capacity} = (\text{number of animals} \times \text{daily manure production} \times \text{desired storage time in days}) + \text{cleaning or leakage water} + \text{freeboard above lowest inlet opening.}$$

Cleaning with high-pressure water may double the volume of wastes. From 20%-60% of the storage volume may be needed for dilution water if the manure is to be distributed with an irrigation system.

Storage Gutters

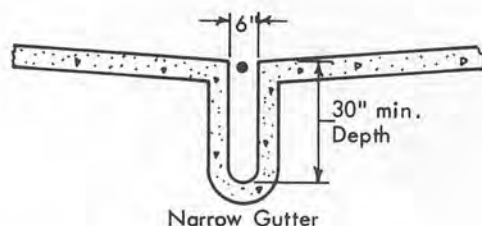
Narrow gutters are used primarily in swine facilities. Wastes from solid floors can be washed or scraped to a gutter for short holding periods. The outlet is usually 6" bell tile with a plug, Fig 313-1. When the gutter is full (usually 3 days to 1 week), the plug is pulled and the manure flows by gravity to an outside storage or lagoon.

Wide gutters are used with swine or dairy. Most of the feces and urine are deposited in the gutter. Wastes can be removed from the gutter daily by a mechanical scraper or frequently by flushing. Larger gutters have greater capacity and can be emptied by gravity or a pump.

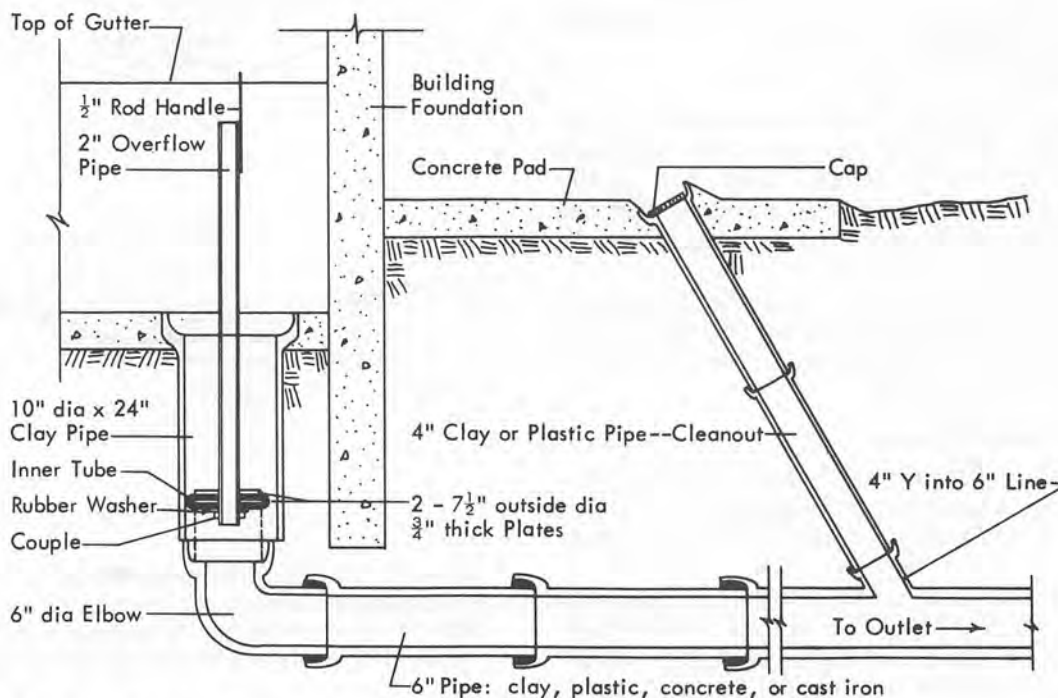
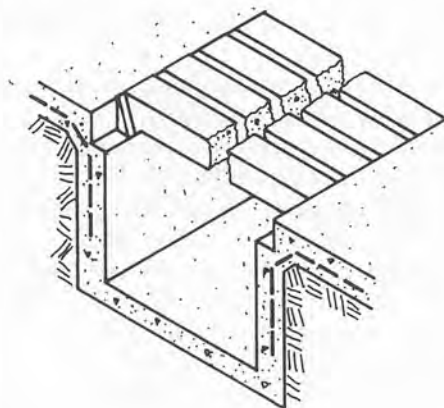
Below-Ground Storage Tanks

Tanks, or pits, fall into three general groups:

- Shallow tanks requiring relatively simple design.
- Large tanks requiring complete structural design.
- Covered tanks, point loaded by scrapers or liquid flushing, either under floors or outdoors. Tank lids, whether solid or slotted, need complete structural design.



Slope bottom of narrow gutter about $1\frac{1}{8}$ ' (1%) to drain.
Slope bottom of wide gutter about $1\frac{1}{25}$ ' (1/3%) to drain.



Drain for liquid manure storage gutter.

Fig 313-1. Manure storage gutters.

Tank depth may be limited by one or more of the following: effective lift of a pump, depth of soil mantle over bedrock, and water table elevation. Overall tank dimensions are unlimited if floor supports (beams, columns) and partitions are used. Columns and beams are commonly spaced 8'-12' apart. Provide agitation access ports, no farther than 40' o.c.

Tanks are designed to withstand all anticipated earth, hydrostatic, and live loads, plus uplift if a high water table exists.

Especially where wastes are stored in a building, and to minimize corrosion, locate the electrical entrance outside the building, and as much wiring and fixtures as possible above the ceiling or behind a vapor barrier.

Shallow tanks are usually in a building and generally about 3'-4' wide and 4'-5' deep.

Design criteria for **deep tanks** are detailed in TR-3, Concrete Manure Tank Design, and TR-4, Welded Wire in Concrete Manure Tanks, which can be ordered from the addresses listed inside the front

cover of this handbook. Typical tank designs are in Midwest Plan Service plan #74303, available from the same addresses.

Note: Obtain approval of appropriate regulatory agencies before starting construction.

Cast-in-place concrete is recommended. Insulate the exteriors of tank walls with waterproof insulation in cold climates. When construction is completed, clean out chips, nails, lumber and other foreign material. As soon as possible after construction, add water to counteract the uplifting forces caused by external pressures from a high water table which can "float" an empty tank.

Protect necessary tank openings with grills and/or covers to prevent children, animals, equipment, or other objects from falling in. Provide removable grills in only those openings used for stirring and pumping equipment. Use grills and covers that cannot fall into the tank, and that discourage unnecessary removal.

"Silo" Storages

Specially designed and constructed above-ground silos are commercially available and used for liquid or slurry storage. They are usually 15'-20' high and up to 60' in diameter, and are filled from an underground pipe discharging into the bottom center.

The above-ground storages are usually agitated by pumping out of the bottom and over the wall to the top. The same pump empties the storage by pumping into a transport.

Earth Solid Manure Storage

An earth solid manure storage is filled with a piston pump for manure with bedding. It is a part of a dairy waste system for cows bedded in stalls or freestalls.

The manure piles up and crusts over, reducing odors and fly breeding. The manure is diluted by rain and snowmelt. Loading from the bottom avoids breaking the crust. An access ramp is needed for a front-end loader. A concrete pad protects the inlet pipe.

Earth Liquid and Slurry Storages

Ponds store material relatively low in solids. Because most solids settle to the bottom, the liquid can then be handled with equipment designed for water if screened inlets are used.

Slurry storages are loaded with relatively undiluted wastes, high in solids and perhaps with some bedding. It is removed from storage with equipment designed to handle slurries.

Undiluted wastes (about 15% solids) must be agitated before pumping into a transport. Some solids will probably have to be removed with a front end loader or similar equipment.

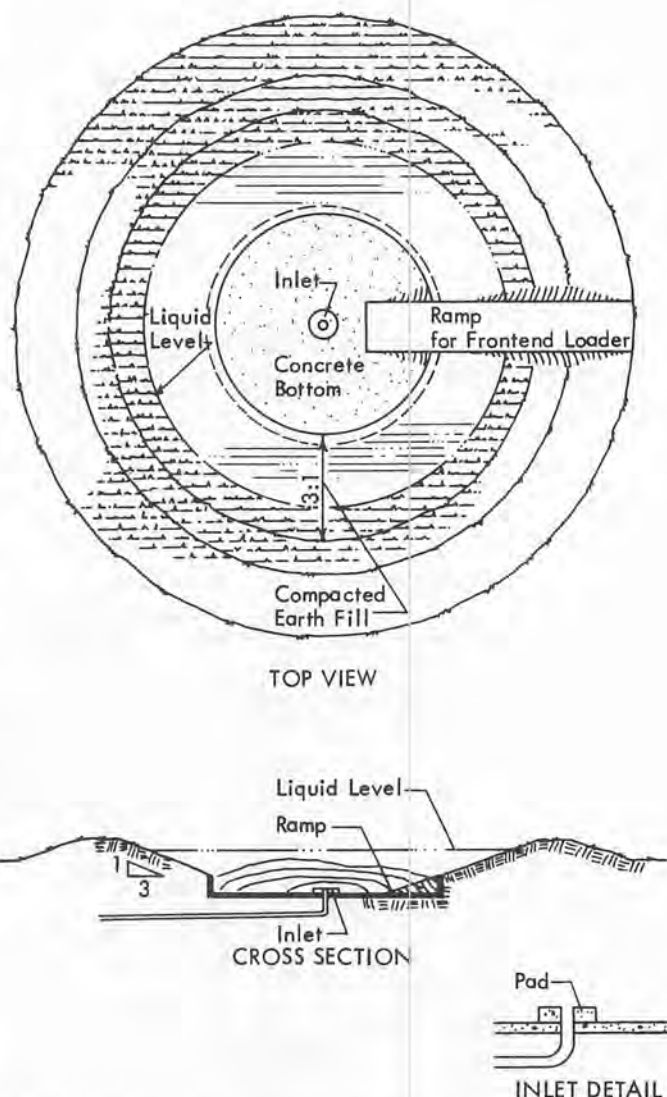


Fig 313-2. Earth solid manure storage.

Solid manure can be stored in an earth basin modified for bottom loading and tractor unloading. Adjust shape to suit site and sideslopes to suit soil conditions.

Access for agitating and pumping equipment can be provided by installing docks from an earth bank or by a concrete apron along a vertical wall of concrete or pressure-treated lumber. Pave part of the storage floor to prevent erosion during agitation. Fig 313-3 a, b.

As with large storage tanks, provide for agitating about every 40'. If the manure has a floating scum, agitate by pumping onto the crust rather than recirculating manure below it.

Provide an access ramp for a tractor, preferably paved, and at a slope no steeper than 10:1 (20:1 preferred). If your pump can operate nearly horizontally, install a transfer pipe at the ramp, park the tank wagon on the bank, and connect the pump to the transfer pipe. Fig 313-3c.

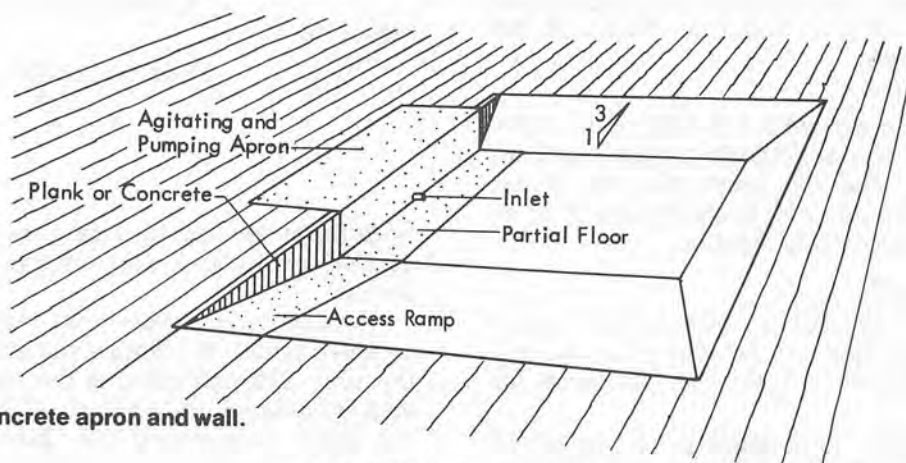


Fig 313-3a. Concrete apron and wall.

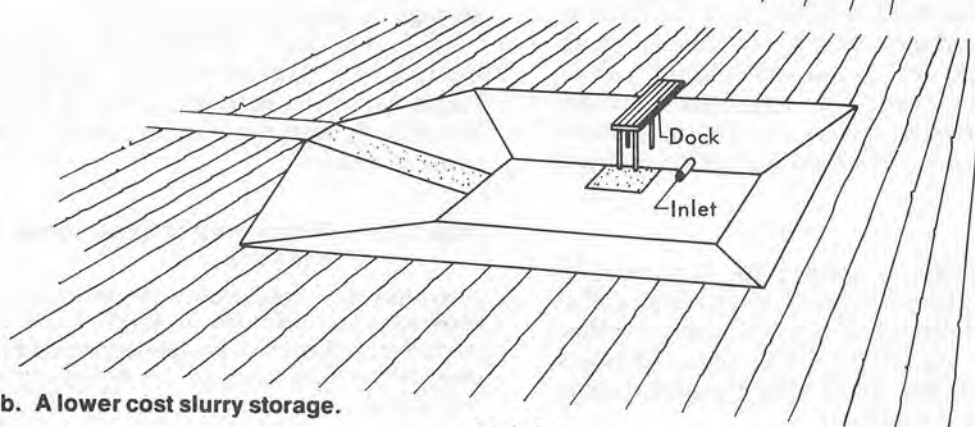


Fig 313-3b. A lower cost slurry storage.

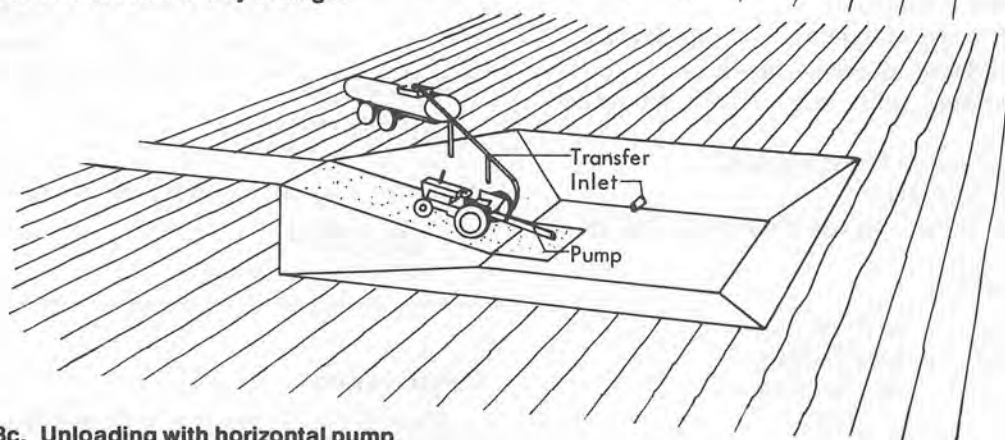


Fig 313-3c. Unloading with horizontal pump.

Fig 313-3. Emptying slurry storages.

Holding Pond

A holding pond is a storage, usually earthen, where lot runoff, lagoon effluent, and other dilute wastes are stored before final disposal. Runoff water is temporarily stored for up to about 180 days depending on local regulations and conditions. Capacity is designed on inches of rainfall on the drained area, such as the 10-yr, 24-hr rainfall. Additional capacity permits labor flexibility—emptying the pond can be delayed without fear that another runoff event will cause overflow.

Other features of a holding pond:

- The bottom and sides are essentially watertight, to avoid possible ground-water contamination. If necessary to seal your soil, first load the pond with some undiluted manure.
- It receives drainage from the lot, usually after it has been through a settling basin, or from a lagoon's overflow.
- It does not receive roof water or drainage from crop land unless it is combined with a lagoon.

- The banks of earth dams are no steeper than 2½:1, depending on soil type. Maintain sod and mow weeds.

Emptying the pond:

- Empty the storage when it is legal and wise—that is, before it is full; when wastes will infiltrate into the soil; when the soil is not frozen, frosted, too wet, or snow-covered; or as specified in applicable regulations.

Solid Manure Storage

Solid manure storages are part of some waste handling systems. They are for solids, liquids, and slurries or for just solids, with other provisions for separated liquids.

Locate storage for year-round access so manure can be spread when field, weather, and regulations permit. Prevent surface runoff water from entering a storage. Provide for convenient filling with a tractor-mounted manure loader or scraper, elevator stacker, blower stacker, or piston pumping system. Unload with a tractor-mounted bucket or manure bucket.

Size

Adequate storage is needed for convenience, saving maximum fertility, preventing water pollution, and to avoid spreading manure when weather or soil conditions are wrong. Up to about 180 days of storage is recommended in cold climates; less is needed in warmer climates.

Determine the size of a manure storage from:

- Number and type of storage facilities.
- Type of manure (solid only or both solid and liquid).
- Type and amount of bedding used.
- Number of animals.
- Number of days of storage desired or required.

Calculate capacity:

$$\frac{\text{Total storage volume required}}{\text{cu ft}} = \frac{\text{Daily storage required per animal unit}}{\text{cu ft}}$$

$$\frac{\text{Number of x animal units}}{\text{x}} = \frac{\text{Days of storage required}}{\text{x}}$$

$$\frac{\text{Daily storage required per animal unit}}{\text{cu ft}} = \frac{\text{Manure voided}}{\text{cu ft}} + \frac{\text{Bedding}}{\text{cu ft}} - \frac{\text{Manure voided but not stored}}{\text{cu ft}}$$

$$\frac{\text{Manure as voided}}{\text{cu ft}} = \frac{\text{Daily raw manure produced per animal unit, see Characteristics, Chapter 311}}{\text{cu ft}}$$

$$\frac{1}{2} \times \text{Bedding used in pounds}$$

$$\frac{\text{Bedding = cu ft}}{\div \text{Density of bedding material, cu ft}}$$

Bedding is compacted during use. An average reduction of one-half the original volume is suggested.

Reduce daily storage required per animal unit by the amount of manure voided but not put into the unit. The reduction is the amount of manure voided outdoors, the amounts of liquids drained off the other storages, etc. See Table 313-1. Increase storage volume for rain and snow.

For stall barn housing, all solids, urine, and bedding are typically stored together. In some barns and some storages, urine is drained off and handled separately; assume about one-half of the urine is removed.

Table 313-1. Proportions of cattle manure in building and yard.

If animals have free access to yard, manure in yard = proportion of manure on yard in the table x total manure/day. If animals are released to yard for controlled periods, manure on yard = $\frac{\text{hr/day on yard}}{24} \times \text{total manure/day}$.

Type of housing	Proportion of manure on yard percent
Free stall dairy	
Inside feeding	50
Yard feeding	60
Manure pack bedded area and yard feeding	
Dairy cattle and heifers	50
Beef cows	70
Beef feedlot cattle	70

Construction

Even for solid manure with bedding, one or two walls to buck against are needed. If urine, snowmelt, or rain is to be retained in the storage, slope the floor down toward one end to assure its retention.

If the urine, snowmelt, or rain is to be drained off:

- Slope floor to one or both sides, with openings on the low side, to a gutter or surface drain.
- Provide floor drains with removable grills. Slope floors toward drains ¼ in/ft (2%). Install underground noncorrosive 6" pipe to carry the liquids away. Or, start stack on 6" of wood or bark chips or corn cobs, to absorb some liquids and to permit the rest to drain.

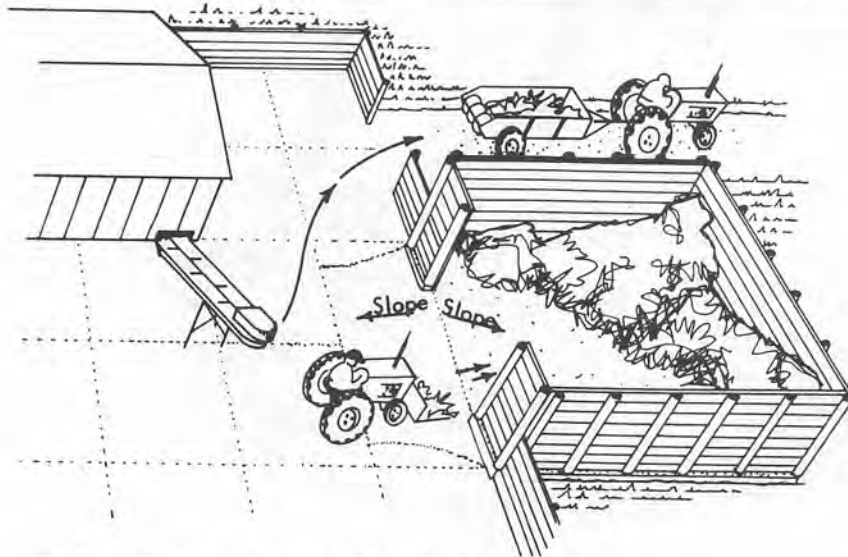
- Provide a gutter to carry runoff away. Use removable covers of pressure-treated wood plank spaced about $\frac{1}{4}$ " apart.
- Start stacking at the high end.

Provide convenient access for unloading and hauling equipment. Provide ramps up to entrances so surface water does not drain into the storage. Limit ramp slopes to 10:1 maximum (20:1 preferred) because traction is reduced for backing out with a

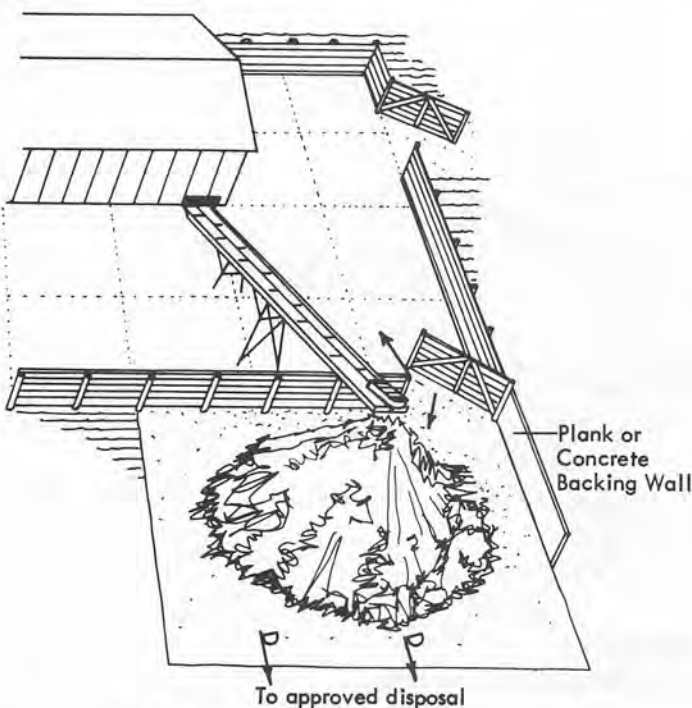
loaded front-end bucket, and attempting to turn on a slope is dangerous.

Walls are usually concrete or post and plank. Concrete floors and ramps are recommended:

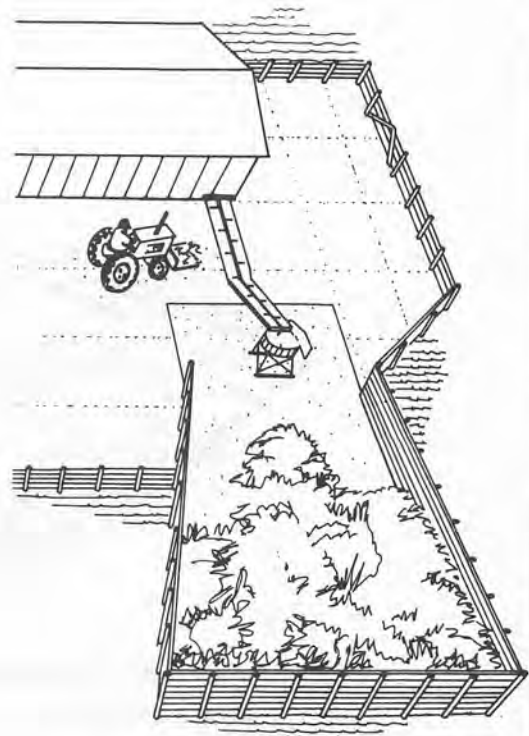
- 5" concrete floor over 6" coarse gravel or crushed rock (up to $1\frac{1}{2}$ " aggregate size).
- 4" concrete floor over 4 mil plastic over gravel.
- 2" sand can replace gravel over undisturbed or compacted soil.



a. Barn cleaner to spreader or tractor stacking.



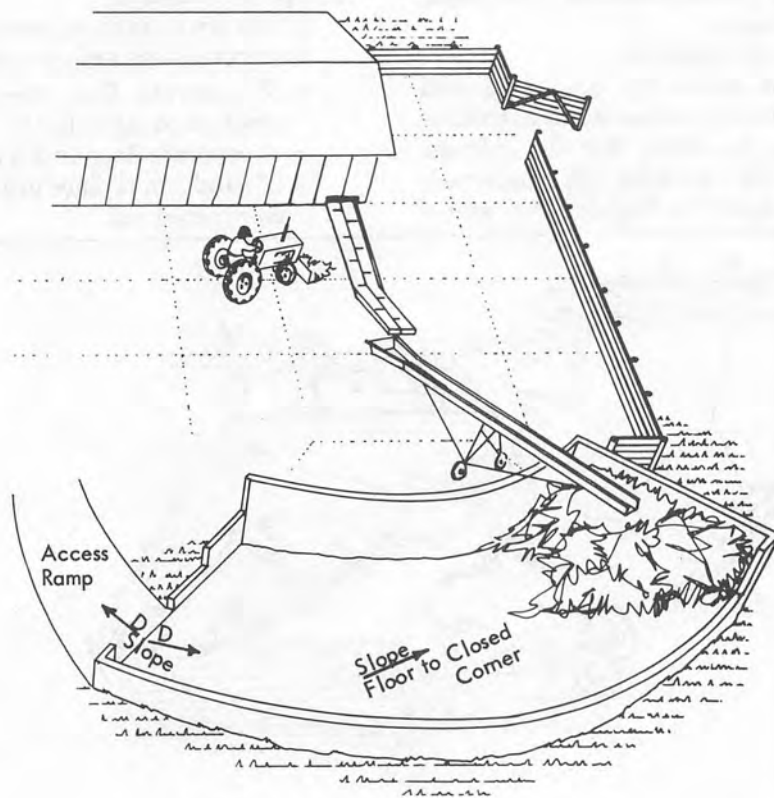
b. Stationary elevator stacker.



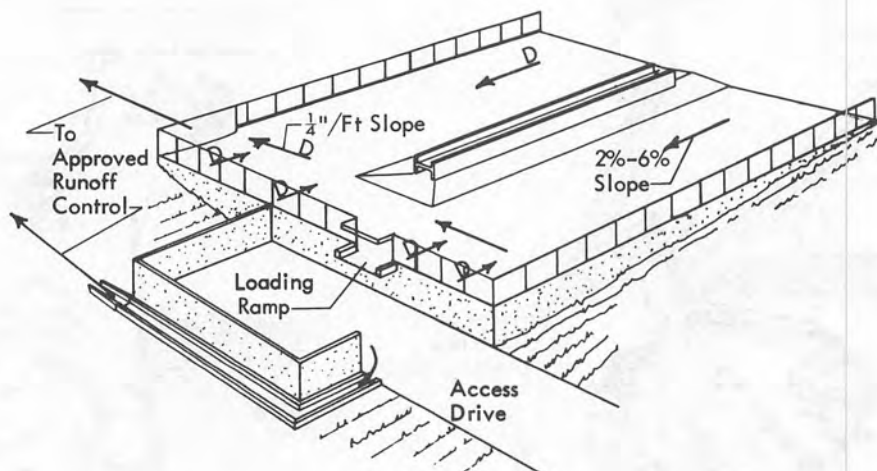
c. Blower-type stacker.

Fig 313-4. Solid manure storage layouts.

Divert surface drainage around lots and storage. Fence cattle away from storage. Divert lot drainage away from storage to approved disposal.



d. Barn cleaner to moveable stacker.



e. Yard layout for sloping sites.

Extend welded pipe fencing around loading ramp for safety.

CHAPTER 314 ANAEROBIC MANURE LAGOONS

Biological decomposition that takes place in a lagoon further liquefies swine, poultry, and cattle manure.

Lagoons are not always successful. They can release objectionable odors, can eventually fill with sludge, and may pollute surface and ground water.

Definitions

Lagoons are treatment structures for agricultural wastes. Lagoons can be aerobic, anaerobic, or facultative depending on their loading and design and can be used in series to produce a higher quality effluent.

Anaerobic processes occur without free oxygen and liquefy or degrade high BOD (biochemical oxygen demand) wastes.

Aerobic processes require free oxygen and although aerobic lagoons require an oxygen supply, their odor-free operation can be a valuable advantage.

Facultative microorganisms can function either anaerobically or aerobically, depending on their environment.

Function

Anaerobic lagoons handle high loading rates, but give off some septic odors. They liquefy and break down manure solids. Not all wastes added are completely degradable. The sludge accumulation depends on management, environment, waste characteristics, and loading rate. After about 2 years, sludge build-up in a properly functioning lagoon may decrease to nearly zero.

Because complete treatment is not practical, anaerobic lagoons are not used alone; pumping or draining is part of the management. The volume of waste and rainfall added is held in a storage volume on top of the lagoon's operating design volume, or the lagoon continuously overflows to a separate lagoon or disposal site.

Where high evaporation rates exceed loading rates and rainfall, water from roof drains and other sources may have to be added to maintain the lagoon's design volume. Mineral buildup, resulting from evaporation of water leaving dissolved salts behind, requires periodic diluting and pumping.

Sufficient land area must be available to dispose of lagoon overflow and sludge.

Well-designed and managed lagoons have a musty odor. Foul odors indicate malfunction. Do not use an anaerobic lagoon where odors may be a nuisance.

Advantages

- In addition to labor saving in removing liquid manure from buildings, further labor is saved by using irrigation equipment and techniques to dispose of liquids.
- The high degree of stabilization may reduce odors during spreading.
- No oxygen is required, and therefore no aeration system is needed.
- Nitrogen reduction is an advantage if disposal must be on small areas.

Disadvantages

- Odors are produced if environmental or management changes reduce biological activity—lagoons are sensitive to sudden changes in temperature and in loading rates.
- Where winter water temperatures are near or below freezing, lagoons go thru spring and fall turnover—that is, bottom water rises and top water drops. After a winter of little bacterial action because of low temperatures, odorous material from the bottom of the lagoon rises to the surface. Further, higher spring water temperatures increase microbial action, and foul odors are generated during the bacterial build-up stages.
- Because higher temperatures improve manure decomposition, anaerobic lagoons work best in summer and in areas without cold winters.
- Fertilizer value reduction is a disadvantage if lagoon effluent is used to fertilize crops. Up to 80% of N is lost in a lagoon. Phosphorous may precipitate to the bottom, but can be recovered when sludge is removed.

Location

Locate a lagoon as far from the farm home as practical, and where the prevailing winds will carry odors away from houses. Court action can force you to revise your waste treatment system to stop the production of objectionable odors. To some people, lagoon odors are objectionable at $\frac{1}{2}$ mile and detectable at a mile or more.

Locate the lagoon near the waste source. If the lagoon is downhill from the source, gravity can transport the waste. A sump and submersible sewage lift pump can elevate wastes into a lagoon if necessary.

Locate the lagoon over impervious soil, where bottom and sidewalls can be impervious. Soil Conservation Service and Agricultural Extension Service personnel can evaluate your soil. Avoid a site where the bottom of the lagoon would be less than about 20' above limestone, depending on soil type. Remove any field tile in the area.

Lagoons on some soils require sealing with liners, clay, or soil cement. Sealing is partly biological—animal waste solids seal many soils—and takes time. Soil or soil cement delays leaking while biological sealing can develop. Membrane sealing (plastic, vinyl, rubber, etc.) is positive and effective, but is expensive and difficult to install.

Consult your Agricultural Extension Service or state health or pollution control authorities for regulations governing lagoon location relative to wells. If the lagoon must be built near a locally recharged shallow well, the bottom of the well should be higher than the top of the lagoon.

Design

Recommended anaerobic lagoon designs result from experience in various parts of the country. Loading rates, which prescribe the lagoon design volume, are based on observations of units with an adequate balance of desirable organisms. Lagoons function best above 70°F and bacterial activity nearly stops at freezing. Lagoons in cold climates require more volume than ones in warm climates.

The minimum **design** volume to provide for each pound of livestock is in Table 314-1. The table relates the period of biological inactivity to ice buildup. The lagoon design volume is the minimum volume times the number of animals, times the average weight of each animal. Other publications frequently cite larger required volumes, but these include allowances for spilled water, sludge accumulation, etc.

Table 314-1. Anaerobic lagoon design volume, cu ft/lb livestock weight.

Cold = considerable ice formed each winter; mild = some ice; warm = no ice. The volumes listed include no allowance for sludge or dilution.

Climate	Livestock			
	Swine	Beef	Dairy	Poultry
Cold	4.8	6.0	8.6	9.3
Mild	1.0	1.2	1.7	1.8
Warm	0.5	0.6	0.9	0.9

Lagoon Size. See Fig 314-1.

Minimum **design** volume provides enough space to maintain adequate bacterial populations. **Always** maintain this volume.

Livestock wastes enter the lagoon regularly—picture them occupying space above the minimum design volume.

Dilution volume is the amount of water that must be added to the lagoon between each pumping period. Dilution water comes from wash water, overflow from waterers, diverted rainfall from roofs and surface water, precipitation minus evaporation on the lagoon surface, and, if necessary, pumped water from a well or water course. Livestock wastes are strong, and unless a lagoon is regularly diluted, it malfunctions because minerals and wastes become too concentrated.

Safety margins include allowance for a 25-yr, 24-hr rain on the lagoon surface when the lagoon is nearly full and before pumping starts. Discharge from this or a lesser storm is prohibited. It also includes freeboard above the emergency spillway so that, should the unexpected happen and the lagoon overflow, the dam will not be destroyed.

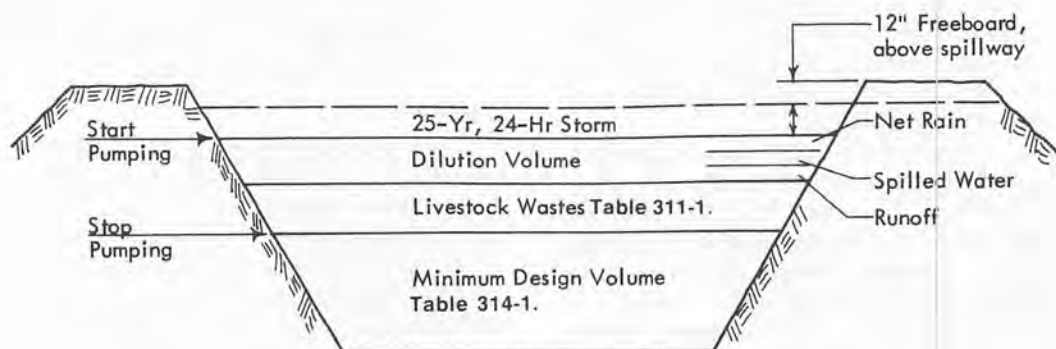


Fig 314-1. Capacity of one-stage anaerobic lagoon.

Procedure

Select **minimum design volume** from Table 314-1 for your livestock and your climate. Multiply it by the number of animals and their average weight.

Decide on a **pumping cycle**. Usually, the lagoon is pumped in early spring (before the water warms up, before much bacterial action starts again, and therefore before high odors have developed), and again in late fall while soil conditions and regulations still permit disposal.

- With twice-a-year pumping, select waste and dilution volumes for six months.
- With once-a-year pumping, select wastes and dilution volumes for one year. Greater storage volume is needed.

Compute the **livestock wastes** expected. Multiply the appropriate number from column 2, Table 311-1, by the number of animals whose wastes will enter the lagoon, and by the number of days (usually 180) between planned pumpings.

The **dilution volume** is one-half the minimum design volume per year.

- Determine net rainfall—the difference between rainfall and evaporation—for your area from Fig 314-2 and 314-3. Excess rainfall provides some of the needed dilution water. Assume rain falls on the lagoon surface and on the banks that drain onto the surface. Assume evaporation only from the liquid surface.
- Prepare to divert roof water, and perhaps surface drainage water, into the lagoon if needed.
- After the lagoon is operational, the level must come up to the dilution volume—if it doesn't, wash water etc. are not providing enough dilution. Divert additional rainwater or pump water from some other source to make up the needed volume before pumping. The lagoon **cannot** operate properly without adequate and regular dilution.

Compute the **safety margin** for heavy rain. Expected rainfall from a 25-yr, 24-hr storm is given in Fig 314-4. Apply this rainfall to all areas that drain into the lagoon, and compute the volume of water. Pump at least down to the "start pumping" level whenever the lagoon approaches spillway elevation, or another storm may cause overflow.

Total lagoon volume is the sum of minimum design volume, wastes volume, dilution volume (usually $\frac{1}{2}$ design volume), and the 25-yr, 24-hr storm volume; set spillway height to provide this volume and build the dam 12" higher for freeboard.

Size of 2-stage Lagoon, Fig 314-5

A 2-stage lagoon needs more total volume than a one-stage lagoon, but effluent from the second

stage is of higher quality. The first cell is large enough to contain the minimum design volume and is kept at constant depth. The second cell is sized for the volume of wastes expected, plus needed dilution volume, plus about one-half the minimum design volume. Because the first cell needs diluting, do not include net precipitation on the second cell as part of the required dilution volume. Do all pumping from the second stage.

Inlets, trickle tubes, and outlets

See Fig 314-6. When planning diversions for surface water, consider that some surface water may be needed for dilution. Locate pumping outlets for irrigation away from inlets, to minimize transfer of unliquefied solids. Extend inlets to a lagoon beyond the cut slope of the embankment to reduce erosion and to uniformly distribute the waste load.

A lagoon may freeze over in very cold weather. If this is likely, either avoid direct loading, or allow enough storage capacity above ice level. With an exposed inlet, increase inlet height to leave room above the ice for winter manure. Or, provide separate manure storage until the lagoon thaws.

Shape

Build a single-cell lagoon approximately square or round to provide roughly uniform loading over the lagoon area, and to allow economical construction and maintenance. Build each cell of a multi-cell lagoon up to 5 times as long as wide. Install inlets and outlets at the ends to assure transferring only wastes that have been in the cell for the design detention time. Consider limiting width to less than 75' so a dragline can remove sludge if necessary. Make the lagoon as deep as practical to limit area needed, to reduce the surface area producing odors, and to increase vertical mixing of lagoon contents. A berm, or dam, width greater than 8' is needed for machine operation; 12' is preferred.

Side slope is determined primarily by soil type, with more stable soils able to maintain steeper slopes.

Management

Fill a new or recently cleaned lagoon $\frac{1}{3}$ - $\frac{1}{2}$ full with water. Add manure regularly, frequently, and in increasing amounts. It is best to start loading in the spring, so several warm months of bacterial action can assure good operation.

After the lagoon is full, divert surface water away to prevent overflow. Maintain the lagoon depth at the designed water quantity.

It is very important to load lagoons continuously—put manure in at least once a week, with once a day recommended. "Slug loading" of large amounts of manure at extended intervals

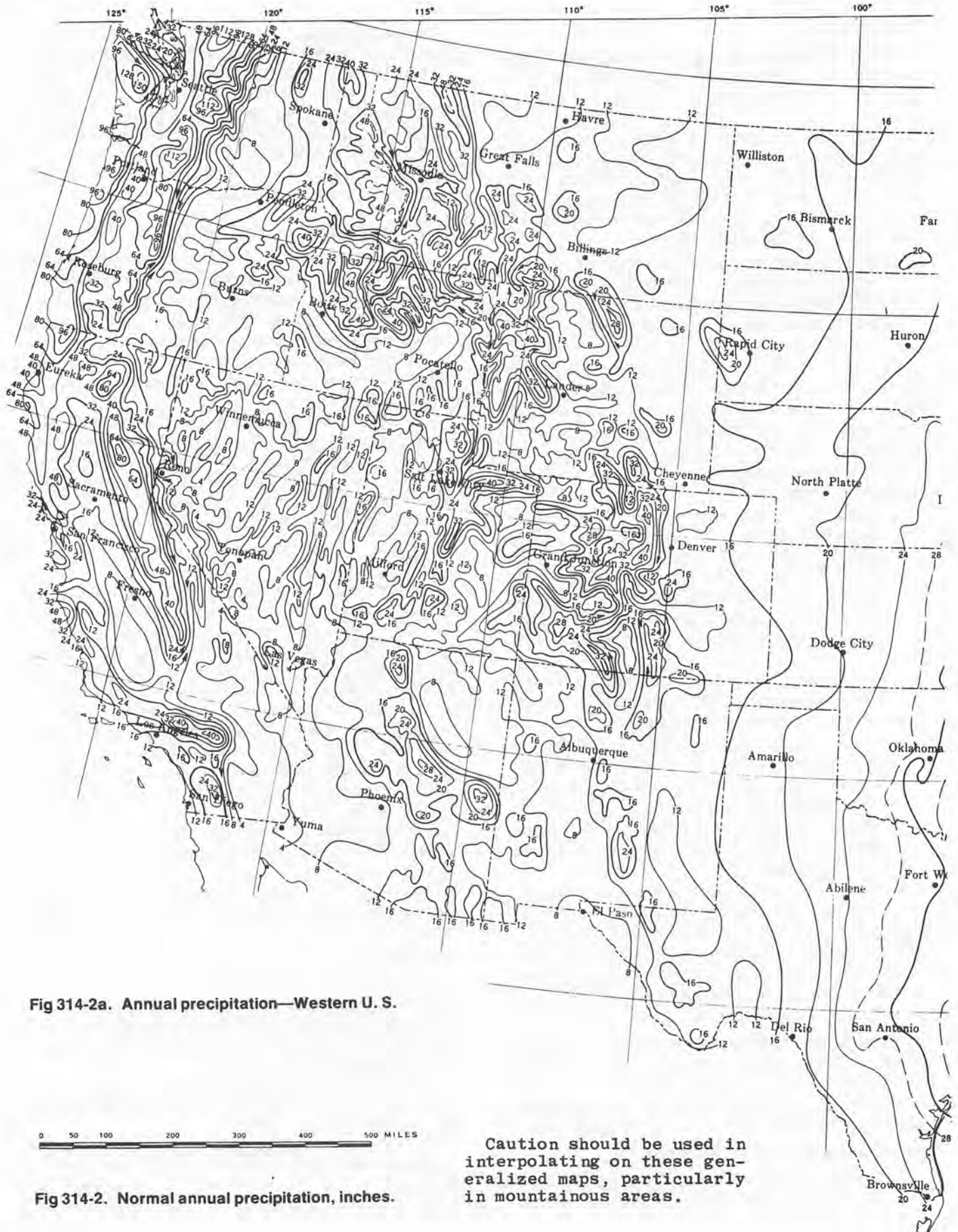


Fig 314-2a. Annual precipitation—Western U. S.

0 50 100 200 300 400 500 MILES

Fig 314-2. Normal annual precipitation, inches.



Fig 314-2b. Annual precipitation—Eastern U. S.

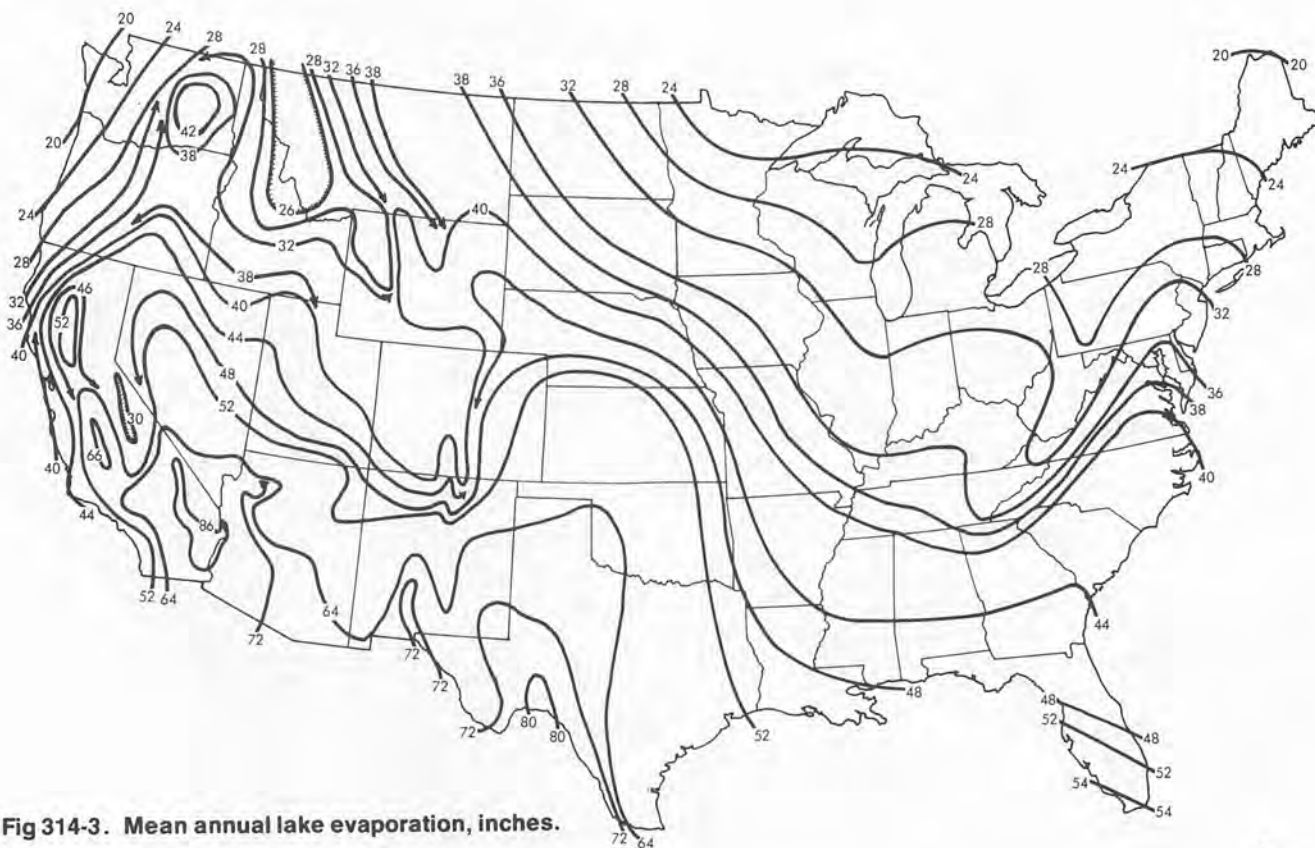


Fig 314-3. Mean annual lake evaporation, inches.

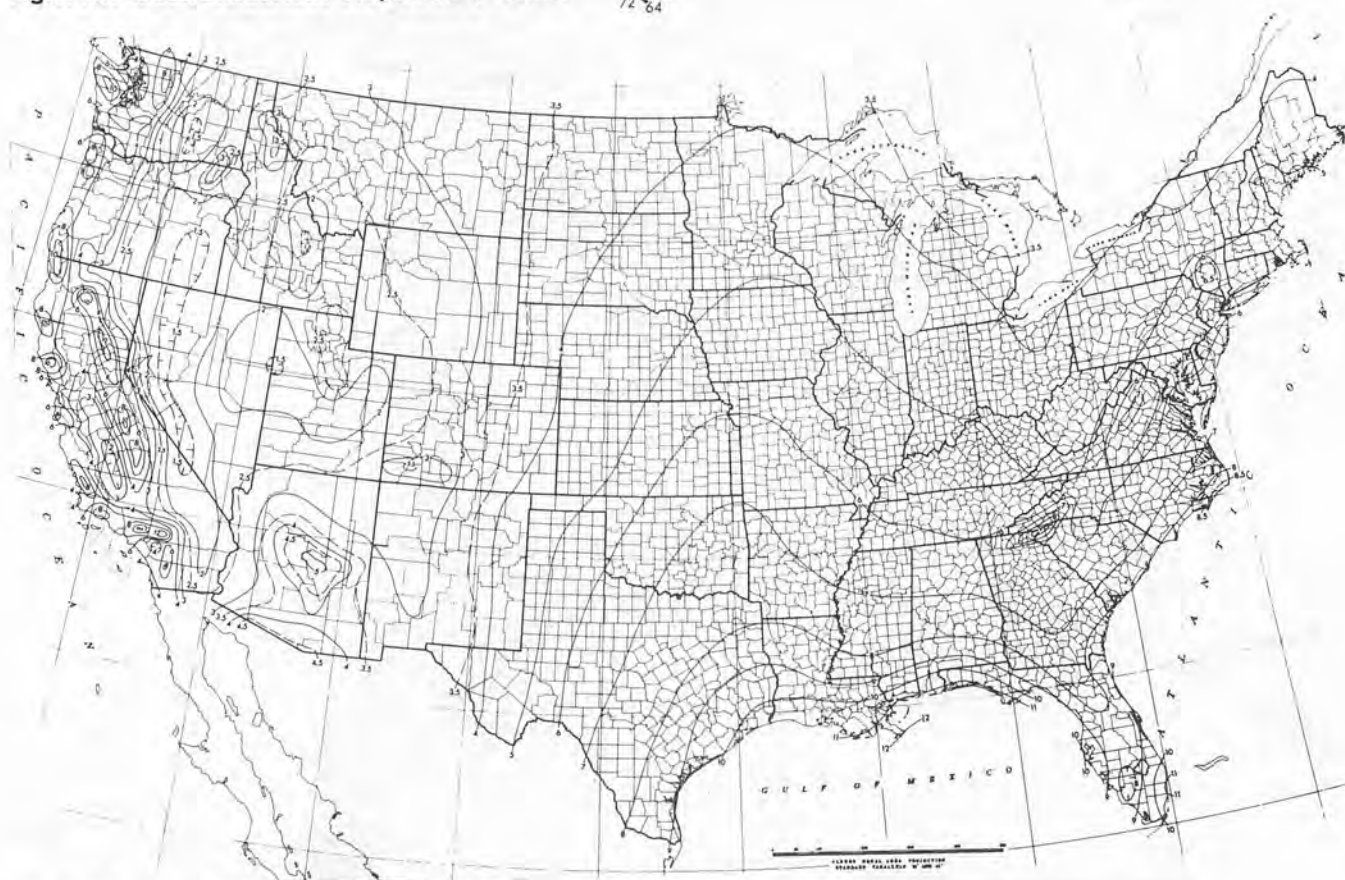


Fig 314-4. 25-yr, 24-hr rainfall intensity, in/hr.

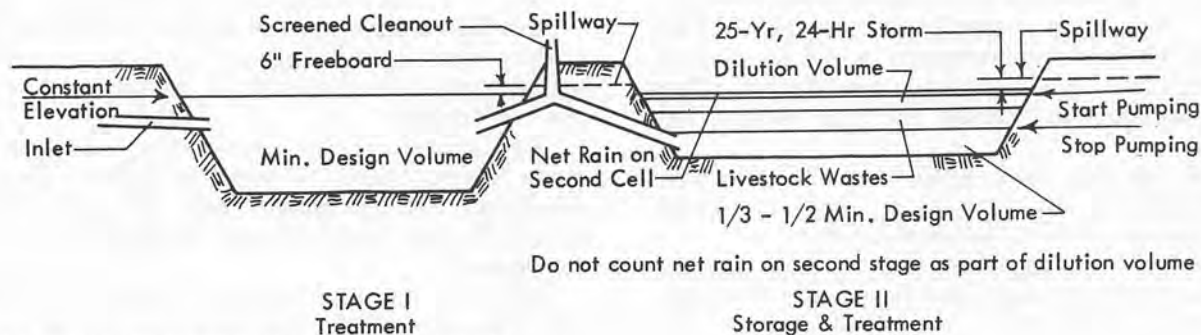


Fig 314-5. Capacity of two-stage anaerobic lagoon.

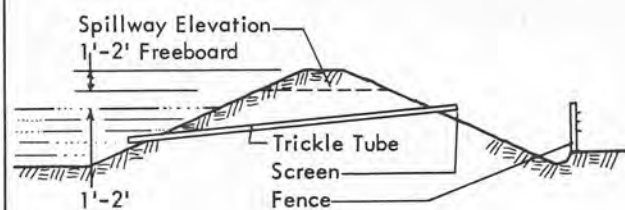


Fig 314-6a. Trickle-tube.

Install trickle-tube with outlet at desired storage liquid level; submerge inlet to avoid its freezing into surface ice. Provide a spillway.

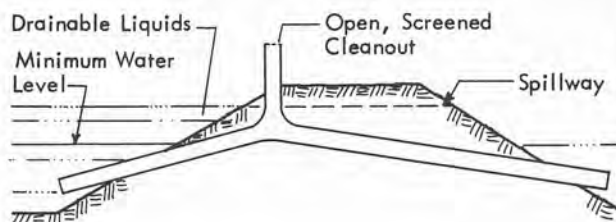


Fig 314-6b. Pipe overflow.

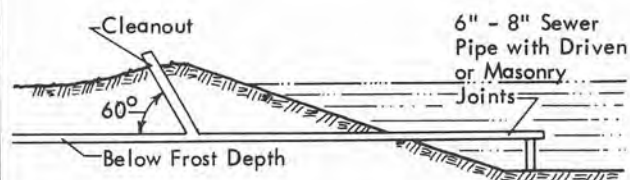


Fig 314-6c. Below-surface inlet.

Use if there is not enough fall between source and storage for one of the preferred inlets. Provide for rodding the pipes.

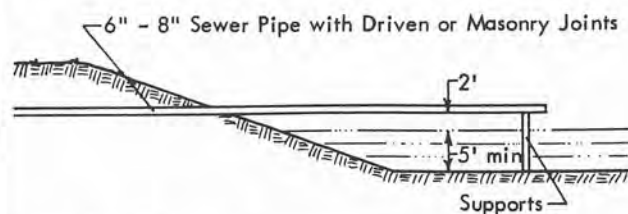


Fig 314-6d. Above-surface inlet.

Best distribution of solids into storage as long as surface is ice-free. Inlet freezing can be a problem.

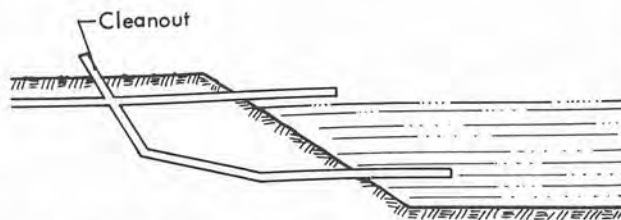


Fig 314-6e. Combination inlet.

Use this outlet if there is enough fall between source and storage. Below-surface outlet prevents freezing of inlets during loading.

Fig 314-6. Inlets and drains for earth storages.

Slope of inlet pipe should provide at least 2 fps velocity with dilute wastes (less than 5% solids).

causes a rapid increase in volatile acids, lowered pH, and high odor. If slug loading is unavoidable, consider a holding tank that can be slug loaded and then emptied gradually into the lagoon. Add hydrated lime or caustic soda to reduce pH changes.

Keep arsenic, copper, antibiotics, and other toxic feed additives out of the lagoon or at a minimum since they may retard biological activity.

With good management, and if design loading rates are not exceeded, lagoons usually establish equilibrium in about 2 years and operate consistently. Odors are usually stronger during spring warm-up.

During the winter, when digestion in the lagoon is very slow, store or haul as much manure as possible to reduce the load on the lagoon.

The best time to irrigate with lagoon effluent is in the fall after crop removal and early in the spring before the lagoon temperature rises significantly. Odor should be minimal at these times of the year.

Use gravel rip-rap around the waterline on steep sloped banks to prevent erosion. Control weeds around the water's edge to control mosquitos. Remove vegetation for 3' above and below the waterline.

Install a fence to keep out animals, children, and trespassers. Post warning signs and keep the gate locked. Seed the bank with low-growing spreading grasses and keep it mowed.

If the manure contains bedding, which is slow to decompose, allow for additional sludge accumulation. Remove sludge when it causes the lagoon to be inefficient.

CHAPTER 315 MILKING CENTER WASTES

Introduction

Management and equipment used greatly affect the concentration and volume of wastes from milking and cleaning operations.

Milking plant wastewater can resemble:

- dilute liquid manure when it contains large amounts of feed, bedding, and hoof dirt—the solids are settleable or will float;
- dilute milk plant wastes during equipment washing—the suspended solids do not settle easily, but the residual cleaning chemicals are usually not concentrated enough to affect subsequent treatment and disposal;
- concentrated milk processing wastes if it contains colostrum, medicated, or spilled milk; or
- clean water during the final pipeline rinse, and while a watercooled condenser is running.

Milk solids include fat, albumin, and lactose. The solids will not settle out and may plug leaching fields and dry wells. It is preferable to dispose of milk solids by field spreading or aerobic lagoon treatment. They can be diluted and treated in an anaerobic lagoon, but may produce strong odors.

Waste Volume

If cow udders are washed using paper towels and a bucket of disinfectant, there is little waste; if cows are washed in an automatic prepstall, water use can be 9 gal/day for each cow milked. Floors can be washed with relatively little water and a stiff-bristle broom, or with a high pressure hose using a relatively large amount of water.

Table 315-1 includes data summarized from manufacturers' recommendations and field observations in several states. Small units tend to use less water, but more per day per cow, for cleaning floors and equipment. A 100-cow unit with automatic washing equipment can use over 800 gal/day, or 3200 cu ft/month.

Typical Systems

Toilet room wastes (including sink, shower, and floor drain) are usually piped to the dwelling, or separate, septic tank. Parlor and milkhouse wastes commonly go into the liquid manure tank or to a waste pond. The effluent from the septic tank can be discharged into a below-ground absorption field. These systems are illustrated in Fig 315-1 a & b.

The system in 315-1c may be suitable when the waste water volume from the milking parlor and milkhouse is low and the soil is very well drained. In some localities health authorities may permit septic tank effluent to be discharged into a waste pond, Fig 315-1d.

Settling Tank

Milkhouse and milking parlor waste contains fibrous solids that plug absorption fields. A settling

Table 315-1. Volume of milking center wastes.

Washing operation	Water volume
Bulk tank	
Automatic	50-60 gal/wash
Manual	30-40 gal/wash
Pipeline	
In parlor (Volume increases for long lines in a large stanchion barn.)	75-125 gal/wash
Pail milkers	30-40 gal/wash
Misc equipment	30 gal/day
Cow prep	
Automatic	1-4 1/2 gal/wash per cow
Estimated average	2 gal/wash per cow
Manual	1/4-1/2 gal/wash per cow
Parlor floor	40-75 gal/day
Milkhouse floor	10-20 gal/day
Toilet	5 gal/flush

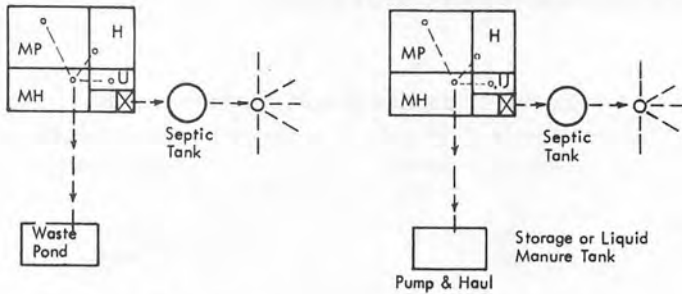
tank can be used to trap this material. Pump out the tank when $\frac{3}{4}$ full of solids. The capacity used is 4 times the water use for one milking period below the overflow level. An approximate capacity is 20 gal per cow milked. The tank should have a length to width ratio between 3:2 and 5:1 to aid settling.

Absorption Field

An absorption field should be used only in well drained soils. Milk solids may plug an absorption field. A soil infiltration rate of $\frac{3}{4}$ gal/sq ft/day can be used to size the absorption field if soil percolation is more than 1" in 50 minutes. Heavier soils than this are not suitable for absorption fields. Estimate the waste water volume per day from the data given in the Water Supply chapter. Divide this volume by the infiltration rate and trench width to obtain the total trench length needed. For a typical 100 cow unit producing 800 gal/day of waste water from the milkhouse and milking parlor and a trench width of 2', 535' of trench is required. A length of 70' is adequate for typical toilet room wastes run through a septic tank.

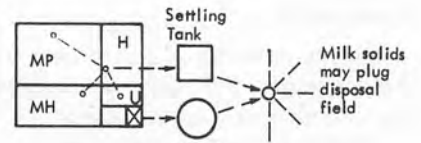
Pipe

Use 4" cast iron, plastic, glazed tile with cemented joints, asphalt impregnated fiber, or cement-asbestos pipe. Lines from septic or settling tanks may be clay field tile if they do not pass within 50' of trees or 100' of a well. Avoid odors with traps and by venting sewer lines using standard plumbing methods.

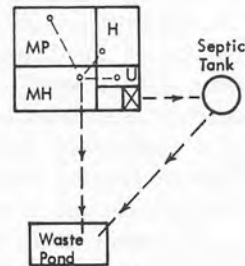


315-1a. Install a sump with pump between the milking center and waste pond if waste will not flow to pond by gravity.

315-1b



315-1c



315-1d

Fig 315-1. Typical milking center waste disposal systems.

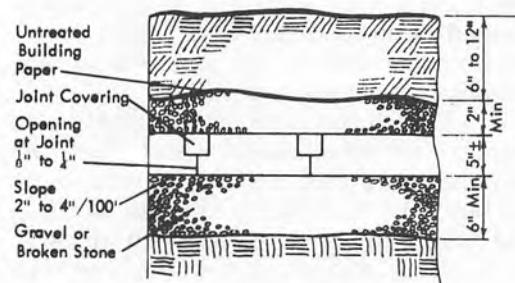
MP = milking parlor

MH = milkhouse

H = hospital

U = utility room

Check with local health authorities to be sure the system in Fig d is acceptable.



Longitudinal Section

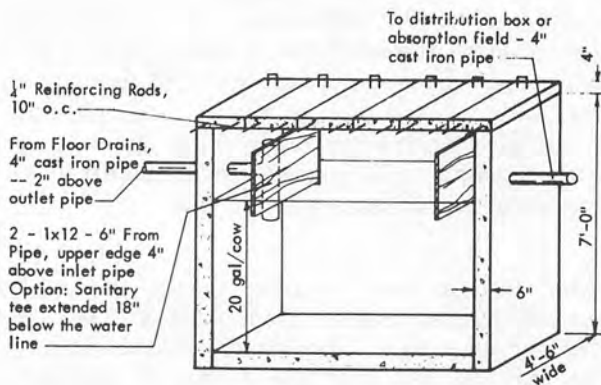
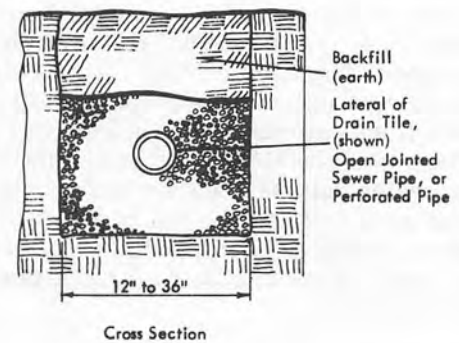


Fig 315-2. Settling tank.



Cross Section

Fig 315-3. Absorption trench.

400 PLANNING

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411 FARMSTEAD PLANNING

Introduction

Farmstead planning usually starts with a problem: Can the old barn be remodeled? How to modernize a waste disposal system? Where to locate a new machine shed? Objectives of planning include expansion, improved performance, higher capacity, and better use of labor.

Careful planning includes reviewing the present, assessing the near future, and providing for the more distant future. It means looking at the whole problem—the whole farm business—as objectively as possible and as far into the future as possible.

Plan on paper, where a mistake is easy to change. Write down your questions, problems, temporary solutions, and decisions, where they are easy to review and hard to forget.

Farmstead planning includes mapping where things are, and evaluating how useful they are. It includes solving problems by designing needed facilities, while allowing as much flexibility as possible for future changes. Seek financial advice on making a cost/return analysis and evaluating the feasibility of any major program.

As you plan, use all the factors; look closely at all farm activities; avoid getting so bogged down in this year's problem that you lose your perspective on future problems. A building in the wrong place is a 20-year mistake; one or two mistakes can prevent your ever reaching an efficient and pleasant farmstead.

Essential Factors

There are four critical factors in any successful farmstead development. They must be considered early and at all later stages of planning. All of the essential factors may not apply to each problem, but they are critical limitations where they occur.

A farmstead needs water.

An adequate supply of water of reasonable quality is essential to all farmsteads. If not available (well, community system, or hauled) do not consider the location for a new or expanded farmstead.

Drainage is essential.

Surface and sub-surface drainage is a top priority factor for several reasons. All-weather drives must be maintained. Feedlots must be drained and waste runoff must be controlled. Prevent surface flow toward the family home. Periodic flooding around any building is intolerable; avoid ponding of rain or melted snow for efficient and satisfactory operation.

Don't Build In A Hole. Modern equipment can move soil to provide drainage out and away from a farmstead.

Production volume—more than space is needed.

Production volume is a key factor in farmstead planning. Doubling the number of animals in a livestock operation does more than just double the space for the livestock itself. Feed storage doubles, machinery inventory increases, vehicular traffic increases, poor chore routes become increasingly more difficult, and services such as water supply and electrical service must be upgraded. Drainage systems become overtaxed. Often supporting facilities such as a calf barn, a cattle handling facility, or a waste management system become essential. Nuisances—odor, dust, noise—also increase. Recognize the full impacts of production volume on a farmstead while considering building or expanding a farmstead.

Off-farm factors.

Farmstead development at a particular site may be limited by off-farm factors. Consider rural housing development; urban sub-divisions; local, state, and federal building and zoning codes; and air and water pollution control requirements. A legal restraint can close your enterprise and may prevent recovering your investment. Clear your plans with appropriate authorities.

Making A Plan

Preparing a good farmstead plan takes time and effort. But, it can be an interesting and rewarding experience for the producer who prepares for decision making. Some "tools" to accumulate are:

Goals—Identify your farmstead goals and set priorities.

Mechanical items—Assemble cross section paper, transparent drawing paper for overlays, a straight edge, a ruler or architect's scale, masking tape for positioning sketches, several colored pencils, and a tablet. For field work: a 50' or 100' tape, stakes, a level, and a hatchet.

Inventory—Prepare a scale map of the farmstead area, showing slope, underground utility lines, building locations, electric power lines, drives, service and road rights of way, and other important physical features. Review present buildings—usefulness, condition, location, and adaptability.

Information—Identify facilities needed, additional services required, traffic routes, feed handling methods, family living desires, and tax and insurance considerations. Establish realistic space requirements for activities and enterprises within the farmstead area. Before a plan is started, read the material in this book. It will help identify many of the factors important to effective farmstead planning.

Developing Your Farmstead

Farmstead planning, once started, is a continuing part of farm management. Adjustments and additions to your plan—buildings, equipment, land, and management—will reflect farming changes. First, develop an accurate plan of what the farmstead looks like now. Then decide what's good and what's bad, analyze current needs, and anticipate future needs.

Your Farmstead Plan

Before starting detailed planning, get or prepare at least one map of any site to be considered.

Aerial photographs are helpful in overall planning before inspection of particular sites. Aerial photos, usually at a scale of 1" = 660', may be available—contact ASCS and SCS offices. Major surface features and improvements show for an entire farm. Or, take your own aerial photos with help from a local pilot. Use a high-wing plane, a good camera with fast lens and film, and several altitudes. Take pictures toward the north, so your pictures will have north at the top, as in most maps. With the sun only an hour or two above the horizon, the longer shadows make the terrain stand out.

Contour maps are useful in planning drainage, building location, and adequate slope for drives, lots, and drainage lines. Your SCS District Engineer may be able to help. U.S. Geological Survey maps give overall contours, but are too small for detailed planning.

A farmstead plan is a valuable planning tool—a large scale and complete details needed. Bring an old map up to date or develop a new one, using the methods shown on page 37. Tape your finished drawing to a table or drawing board. Lacquer-type hair spray helps prevent pencil lines from smudging. Tape a sheet of tracing paper over your plan. Experiment and guess on overlay sheets to save your "as-is" plan.

Use several different overlays and return to your plan from time to time to think of new arrangements that may be better. Planning on paper saves time and money. Take proposals to the field for a visual check. Look for ideas on other farmsteads with situations similar to your own. Stake out proposals. Use a 100' tape and stakes—wood or stiff wire with bright plastic flags—to mark corners and boundaries. Lay out a proposed road, building, or distance zone to help visualize your revised farmstead. Binder twine can show building walls or sides of lanes.

Zone Planning

Zoning, as in Fig 1, is a useful tool in planning new or remodeled farmsteads after the general site has been selected. Although 100' wide zones are shown, wider ones are often desirable.

For a farmstead with a family living area, place the house at the center of the planning zones. For a farmstead without a house, the farm court is usually the center, because vehicles, materials, and labor tend to work from the court.

Tape tracing paper over on your map, draw circles about 100' apart using the house (or court) as center. These 100' bands are activity zones, and they help locate major activity areas, help preserve a desirable family living environment, and they encourage spreading the farmstead out, leaving space for present operations and future expansion. See Fig 1 and 2.

Zone 1—Family living. Lawns, recreation space, flower and vegetable gardens, and guest parking are close to the house. Protect Zone 1 from noise, odor, and dust as much as possible.

Zone 2—Machinery center. Shop, storage, and related services that are relatively quiet, dry, and odor free are in Zone 2. Consider screening the center from family view.

Much of the driveway and farm court may be in Zone 2. Put fuel and chemical storage toward the outer edge—near the machinery, but removing odors, fire danger, and some hazard to children perhaps 200' from the home.

Zone 3—Grain, feed, and some livestock. These areas cause dust, noise, traffic and odor, and are therefore moved another zone further from the house.

Grain and feed handling and processing require electric power and good vehicle access. But, keep heavy equipment, large dryers, and fire hazard away from the house. Zone 3 is a compromise.

Small animal units may also be in Zone 3; that is, small animals or a small number of animals may not seriously degrade family living. A livestock unit close to the house is convenient for active management of maternity and nursery units or for care of pet or hobby animals.

Zone 4—Major livestock facilities. A large unit, whether confined to a building or on drylot, creates demand for adequate space, drainage, waste management, access, loading facilities, feed distribution, and other services. It also creates noise, dust, traffic, and odors. Space for expansion is usually important. Locate major livestock production in Zone 4 or beyond.

Moving away from the old farmstead is frequently the most economical, as well as satisfactory, way to solve major expansion problems.

Zone planning applies to both cash grain and livestock farms. A grain farm can become a livestock farm and vice versa, so allow for both grain and livestock in your master design, to protect future growth, efficiency, and sale value. Adjusting to changes in health, labor supply, or economics can be difficult unless space is available for expanded and new facilities.

Planning Factors

Distance factors

Distance factors help locate one activity relative to others.

Management requirements of an activity may suggest how close it should be to the court or living center.

Compared with large numbers of finishing or adult animals, young or small animals produce less odor and waste. But, because they usually need more supervision, keep them near the office or court. They also tend to be in buildings that are easy to landscape and less objectionable to view.

A grain farm usually requires less farmstead space than a grain and livestock farm. Livestock on pasture affect farmstead design far less than confined livestock. Also, the noise and dust of moving cash grain for a relatively short time once a year has a different impact on the living center environment than daily livestock feed processing.

Size of enterprise also affects distance. While a relatively small livestock operation may be in Zone 2 or 3, locate a large one further away, even though it requires more management. A feed center for processing a few bushels a day may be less objectionable if near the living center than one often handling large trucks and large volumes. Doubling grain acreage usually has less impact than doubling a housed livestock enterprise.

Pollution of air or water by some farm activities cannot be completely controlled with present technology. For instance, large confined livestock enterprises create waste disposal problems and undesirable dust and odor. Farm chemicals, including fertilizers, pesticides, and fuels, can cause pollution if improperly handled. The living area environment is improved if potential pollutants are kept some distance away.

Nuisances include noise, dust, chaff, insects, and heavy traffic. Locate annoying activities so they do not detract from the safety or quality of living for you or your neighbors.

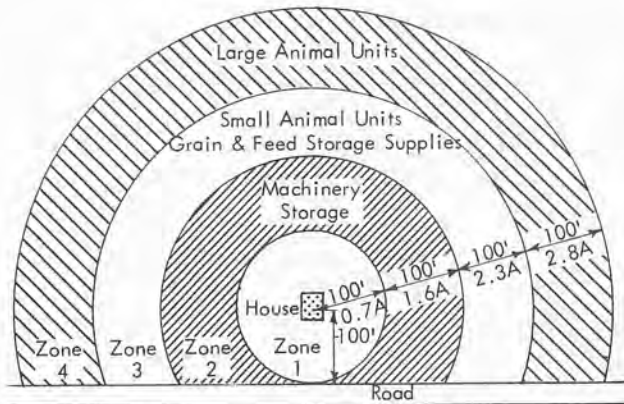
Minimize nuisances with good management, and by placing Activity Centers in the zone suggested in Fig 1 and 2 and downwind from the house.

Appearance—a neat, attractive farmstead—is an important and worthwhile goal for many farm families. Although paint, lawn mower, and labor can improve farmstead appearance, a good design also helps.

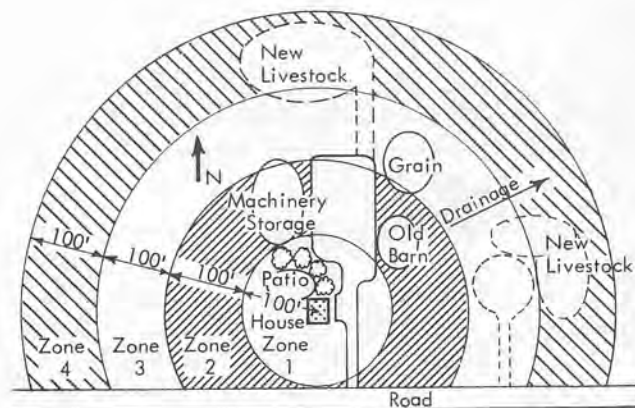
Topographic factors

Topographic factors are concerned with "the lay of the land."

Site selection is finding the best location available for an enterprise with enough space, good drainage, access to water and other utilities, and proximity to other farm operations. Also consider view, access, neighbors or other commercial operations, and utilization of existing topography.



1A. Four planning zones.

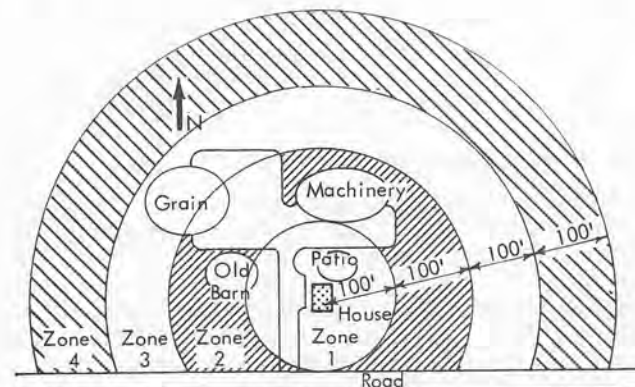


1B. Example: livestock enterprise north of the road.

Major centers: living, livestock.

Secondary centers: machinery, grain.

A separate drive could serve a new large livestock unit.



1C. Example: grain enterprise north of the road.

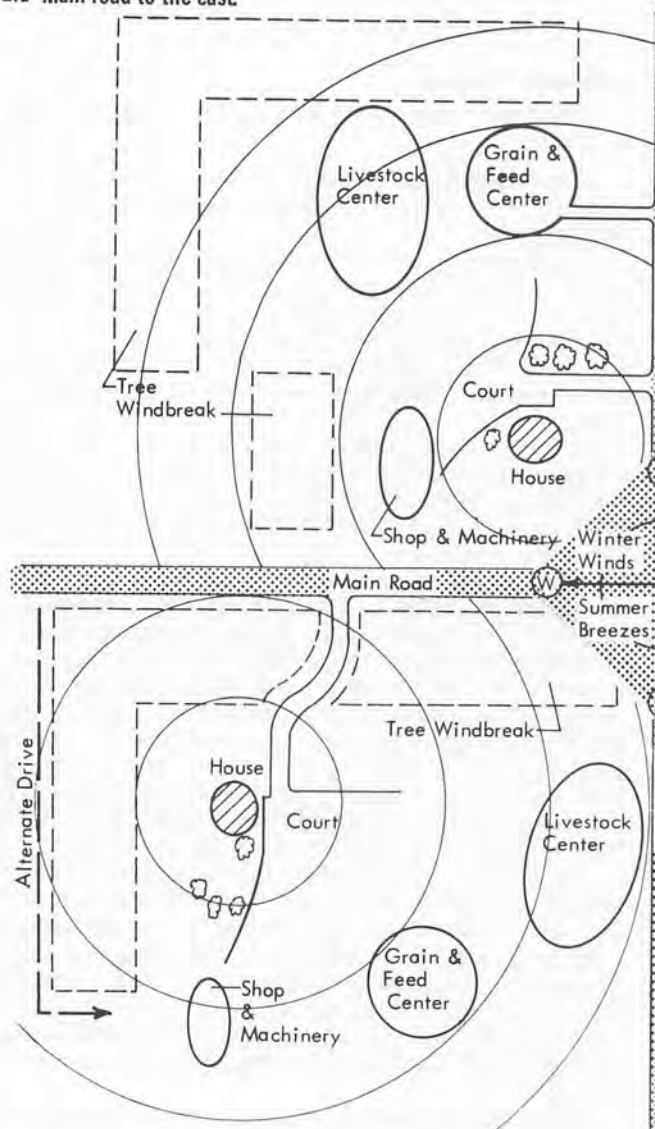
Major centers: living, grain.

The machinery and supply areas are positioned for convenience and accessibility.

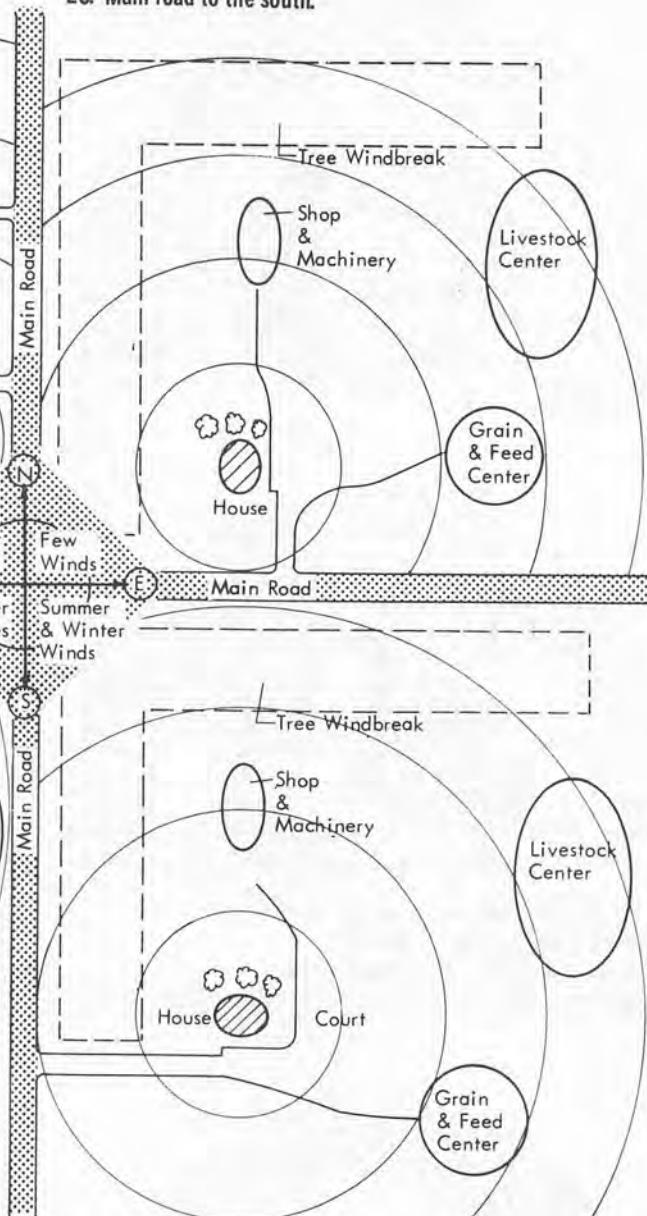
Fig 411-1. Farmstead planning zones.

Each zone is 100' wide—less space may lead to crowding, but wider zones are often desirable.

2A. Main road to the east.



2C. Main road to the south.



2b. Farmstead south of the road.

Fig 411-2. Farmstead and main road relationships.

2d. Farmstead east of the road.

When looking for a site, consider the largest area you might need—and then double it. Such an area may look too large, but future expansion may need more space. Also consider separating the farmstead into two sites—moving the house to another site, or developing a new remote area for a major livestock center. Avoid flood plains, swales, low ground, and peat or very rocky soils.

Drainage—overall surface and subsurface—is one of the most important features of an effective farmstead. Natural drainage is preferred, but some drainage improvements are usually needed. Select a site that avoids surface water flowing toward it. To minimize drainage problems, intercept and divert surface water that flows toward the farmstead. Surface drainage away from the house helps keep the living area and basement dry.

Slope of the land provides surface drainage. Ideal slopes range from 2%-6%—steep enough to drain but not enough for excessive erosion, depending on soil type. If no available site has such slopes, locate the farmstead where it meets most other criteria and grade as needed to get the desired slopes before building. South slope exposure is desirable for natural drying and is especially desirable for livestock feeding areas.

Within the farmstead, locate buildings on relatively high ground. Provide surface drainage away from foundations. Provide all-weather traffic routes between activity centers, using drainage ditches and culverts where needed, to assure access even in very wet weather.

Sub-surface drainage is needed for dry basements, grain elevator pits, and below-ground storage of

wastes or silage. Drainage around foundations reduces frost heaving by keeping soil moisture below saturation, and reduces soil pressures on foundation walls. Drainage from waste facilities and silos must not pollute underground, drain tile, and stream waters. Avoid sites with springs, wet weather seeps, or high water table.

Enough space is needed for all major farmstead activities, and for expansion. Leaving space for growth and future change is more a question of planning than of cost. Avoid locations near a river, section-line corner, rough topography, or other feature preventing expansion.

Climatic factors

Proper design and arrangement of farm buildings can help minimize the bad effects of climate and take advantage of good effects.

Wind increases both summer comfort and winter discomfort. It carries dust and odors, and causes snow drifting.

Although wind blows from all directions, the most common summer and winter winds are important in farmstead planning.

Put odorous and noisy facilities downwind of the living areas of the farmstead and its neighbors. How far downwind is suggested in the discussion of Distance Factors. Face open front buildings away from prevailing winter winds.

Sun heat is useful energy in cold weather—it warms buildings and helps dry surfaces. In hot weather, livestock need protection from direct sun heat.

Rain and snow, while essential to agriculture, create drainage, drifting, and erosion problems.

Design for the major snow or rain storm and your farmstead will handle minor storms with ease. Severe runoff can flood buildings or lots, or can wash out roads and utilities. Get design assistance through your county's extension office, the SCS District, or consulting engineers.

Diversion terraces, dikes, and drain tile collect and direct runoff from rain and melting snow. Minimize runoff to be handled by the livestock waste management system; divert "clean" water away from livestock lots with roof gutters and diversion terraces. Located properly, windbreaks can reduce major snow problems.

Service factors

Services are the connecting links between farmstead buildings and activities; they help the farmstead operate efficiently.

Drives and lanes are crucial to farm operation. Their surfaces should be firm, well-drained, and wide enough for large machines. Provide all-weather access to all activity centers.

Utilities

Make a utilities overlay for your farmstead map. Draw in the path of each overhead and buried wire and pipe. Include electric and telephone lines, water and sewer pipes, septic tanks, drainage field,

and gas and drain lines. Use colored pencils or pens, and dashed, dotted, and solid lines to identify each utility.

Record enough dimensions to positively identify the location of each underground utility. For example, show exactly where water and electric services enter on an outline of a building. Indicate the type, size, and depth for each utility.

Water—of adequate quality and quantity—is essential to a farmstead. Water can be piped considerable distances if necessary. Consider installing a remote storage tank that can be filled with a relatively small pump, yet still meet peak water demands. Each farm water system is unique, but if water is available, good design will provide a dependable and high-quality system.

Electricity distribution policies vary with different power suppliers. Your supplier's power use adviser can help with comparisons of overhead and buried lines, locations of main lines and power drops, and recommended yard lighting.

Gas installation should also be planned with a supplier's representative. Locate LP tanks for easy servicing and maintenance, and to minimize the danger of fire or explosion. Check insurance company and state regulations or limitations.

Telephone service is an important farm business tool. Contact your phone company before constructing a major building; it may be possible to reduce installation costs and have more satisfactory service. Phones in more than one location permit handling business calls away from the house, and may permit calling a fire department with one or more phones inaccessible.

Fire prevention is the best protection. Prevention includes adequate wiring, good housekeeping, properly maintained heating equipment, lightning protection, proper storage of fuels, and avoiding spontaneous ignition. Spacing buildings at least 50' apart reduces fire spread and permits access for firefighting.

Equip each building and the fuel center with portable fire extinguishers at entrances and high-hazard areas. Provide water for fire department use from a pond or emergency cistern.

Safety of people and animals from fire, natural hazards, and accidents is part of all design decisions. Some items are suggested throughout this book. But, a general awareness during planning processes is helpful; movements (machinery, vehicles, animals, falling or wind-blown objects), heights (ladders, pits), surfaces (ice, slick floors), and materials (chemicals, fuels, bulk grain) suggest broad categories of risk.

Federal safety legislation requires owners to plan and operate their businesses as safely as possible. Consult state safety authorities for answers to specific questions and for applicability of the Occupational Safety and Health Act.

Security is a difficult problem—farms are vulnerable to theft, vandalism, arson, assault, etc. Be alert for protective measures and available equipment, and cooperate with local authorities. Consider fire and theft alarms, and night lighting.

Planning Activity Centers

A major problem in planning on a present farmstead is overcoming too much familiarity with how things have been. We tend to work around that road, or this fence, or that building, pump, or mud-hole without questioning.

Look ahead as far as you confidently can, and then at least double the size of the facilities you see. Think big about space, mechanization, processes, and operational changes that might occur, so you or the next generation will be ready if such growth develops. A good farmstead plan for twice an expected growth can be scaled down to fit current needs and finances. And, your design will leave space for future storage, processing, or livestock facilities.

Family living center

The family living area of a farmstead includes the house, lawn, patio, play areas, garden, garage, guest parking area and a portion of the drive.

Essential Factors

Water, both potable (of drinking quality) in the home, and of reasonable quality for outdoor use, are needed in the living center. Special needs of farm families include family clean up and wash up near the service entrance and, commonly, relatively large vegetable and landscaping gardens that may require watering.

Drainage around a farm home is especially important. Surface drainage from other areas may be polluted and odorous. Water around the house may prevent a dry basement. Recreation areas may be useless mudholes in wet seasons.

Site location for the house affects neighbors less than do major production activities. However, avoid nuisances from neighboring farms, and consider the home site relative to other land uses.

Special factors

It is desirable that the house be the first building seen, or at least approached, both for appearance and for control over traffic and visitors.

When adding a house or developing a new farmstead, locate the house first, considering all the factors discussed in this section. A pleasant living environment requires using the advantages of rural living—space, privacy, view—while avoiding the disadvantages of being near a busy business center with some undesirable by-products.

Locate an office in the house near the service entrance. Business guests need not walk through the house to get to it, and you can come and go from outdoors without disrupting household activities.

Provide for outdoor family activities as the family living center is developed. For example, a patio and play area can be shielded from the farm court and from the road by the house, a garage or fence, plantings, or any combination. But, easy access to a patio from the kitchen is desirable for outdoor meal preparation.

A fenced play area for small children protects them from farm activities and stray animals, and keeps them from wandering to possibly dangerous areas. Fencing or shrubbery can hide garbage or trash storage.

Locate a second house as carefully as the first, with relations between two families an added concern. Perhaps a completely separate site is best if another desirable homesite is available on the farm. If two or more houses must be relatively close together, a separate entrance drive gives some feeling of privacy and tends to separate visitors. At least provide for visual privacy with plantings and house orientation. Arrange play and outdoor living areas for visual privacy; plantings can help control noise.

Distance Factors

Quality of living is especially vulnerable to inadequate distance from farm production centers. Zone planning of farmsteads including a living center is based on the position of the house. Generally, keep the house at least 100' from a road to allow for possible road widening, for a buffer against noise and dust. More setback is needed if a tree windbreak is between the house and the road.

Locate the house upwind from livestock facilities to avoid odors carried by prevailing winds.

Topographic Factors

Space is needed for the house, drive, family and guest parking, outdoor living, and for separation from neighbors and farm operations.

Locate the house where the view from the kitchen includes the farm court and the drive from the public road. Make the view from the living room the best your site offers; consider plantings that frame the desirable view and hide your neighbor's barn.

Climatic Factors

Where a tree windbreak (shelterbelt) is grown, include the family living center inside the protected zone but outside the area of major snow catch. Most snow usually accumulates within 185' of the windward row of trees. Provide additional wind protection with screening fences or plantings, but avoid blocking desirable summer breezes and causing snow drifts at walks and drives.

Service Factors

Drives and parking are among the more important features of a successful farmstead, and are discussed in the section on Planning Services. Planning details, and discussion of utilities and other services, are discussed in the same section.

Machinery Storage, Repair, and Service

The farm shop is usually near the machinery storage, either attached or in a separate building.

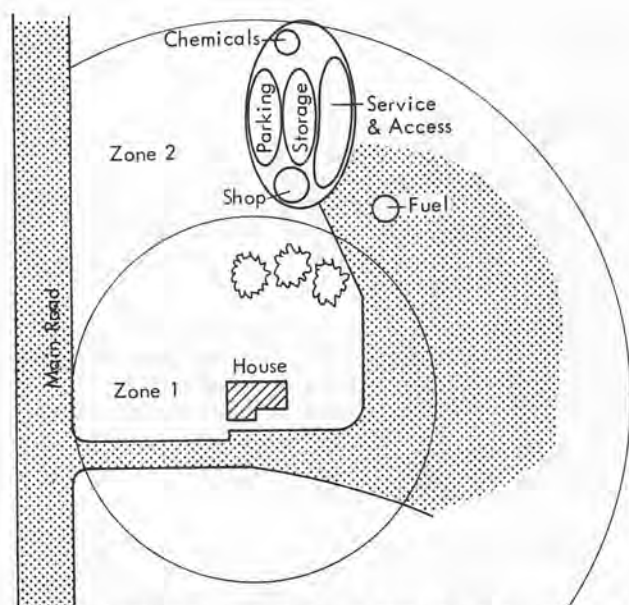


Fig 411-3. Locating shop, machinery storage, chemical storage, and fuel center.

A separate building reduces fire hazard. Some repairs are made in the storage area adjacent to the shop when the shop lanes are filled.

The shop and part of the storage can be built now with more storage added later. If you have adequate machinery storage, consider a separate shop, located so more machinery storage can be added later. Machines parked in front of the storage can be screened from view with trees and shrubs. Face machinery storage doors away from a public road for better appearance, safety, and security.

Provide a 40'-50' wide improved servicing area in front of the shop. Some machines can be stored behind the shed, perhaps in the snow-catch area of a tree windbreak except in winter.

Fuel, Chemical, and Fertilizer Storage

Consider a farm service station, with fuel storage and pumping, oil, water, and compressed air. Because major equipment needs space to maneuver around the fuel pump, and because it is wise to separate fuels from a building, a fuel center about 50' from the shop fills both a service and a safety need.

Provide gravel or hard-surface access to the fuel pump from two or three sides. Slope the ground away from the fuel center so rainwater and fumes can drain away. Provide lights and a dry chemical fire extinguisher (fire type B) at the pump. Lock fuel pumps for safety and security.

Fertilizers and pesticides create other storage problems. Ammonium nitrate is explosive if contaminated with fuel, oil, or other hydrocarbon or organic material. Some insecticides and herbicides can contaminate each other or fertilizer; some are flammable. State law may control storage, use, and disposal of some products.

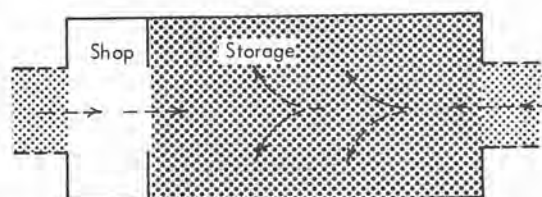
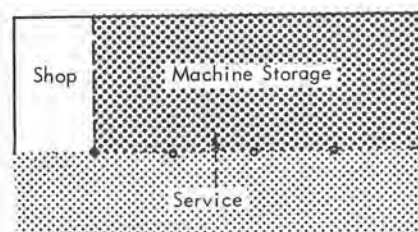


Fig 411-4. Access to machinery sheds.

Leave space for expansion at one end of the storage.

The chemicals center is convenient if near the shop and machinery center, but move it as far as reasonable from the house because of odors and child safety.

A chemicals center requires water for mixing, and an outside frostproof hydrant for filling sprayers, emergency flushing of eyes or skin, and rinsing utensils and containers. Electricity is needed for lights, ventilation fans, and perhaps heat for winter storage of liquids.

Do not provide batch storage containers for chemicals; store them in their original containers so they remain identified and with instructions for their care and use. Provide for disposal of wash-water.

Grain Storage and Processing

A farm grain-feed center needs electric power, vehicle access, room for expansion, reasonable drainage, and proximity to livestock areas if the facility is for both storage and feed making.

Essential Factors

Some water supply is needed for washing, dilution, and perhaps fire control.

Drainage must permit all-weather access. A deep dump pit requires good sub-soil drainage.

Increased capacity or revised management may increase noise and dust levels, and their impact on neighboring areas. The amount and kind of vehicle traffic may also change—consider road and bridge capacities required to support your needs.

Distance Factors

Feed and grain facilities are located in zone 3, or even farther from the house, because of noise, dust, and traffic. Space around the center is needed for access and vehicles—often semi-trailer trucks.

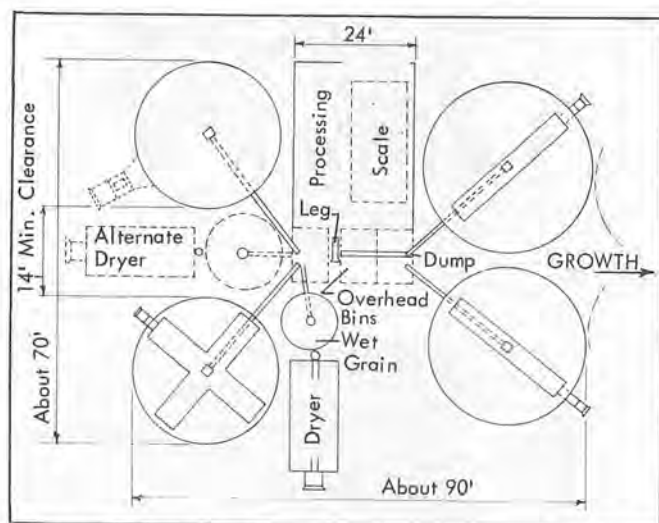


Fig 411-5. A grain and feed handling center.

The center has one side relatively fixed in size—dryer, wet holding, handling equipment and working bins. The other side is left clear for growth as new storages are added.

Topographic Factors

Put a grain-feed center on a crowned or graded area with good surface drainage away from all facilities. Good sub-surface drainage aids in designing an elevator pit, some conveyors, and foundations. Roads must be usable by heavy vehicles in all weather, so good surfaces and space to store plowed snow are needed.

A four-bin grain handling facility with center building, drying, and storage for up to about 40,000 bushels requires an area about 100'x100', plus room for vehicles to approach and leave.

Service Factors

On livestock farms, all grain may flow into a grain-feed center for storage and processing before being conveyed out later by vehicle or mechanical conveyor. Large bulk delivery vehicles, even semi-trailers, may need access.

Some cash-grain operators will load 800 to 1,000 bushel semi-trailers or 4-wheel trailers behind a straight truck. Driving through, rather than backing up, is essential; ample turning space is needed.

The weight of grain transport trucks may affect locating the feed center to avoid light-load bridges or culverts. Putting a grain center in a remote location may mean developing and maintaining an extra road and more distance for providing utilities. But, it also means less nuisance in the living area.

Especially on cash-grain farms handling over about 50,000 bushels per year, separate receiving and load-out drives may be desirable. Efficiency suffers when a loading truck blocks the receiving dump for extended times at harvest. If feed delivery wagons or trucks operate daily, a separate load-out lane avoids plugging grates and pits in the receiving alley, and avoids cleaning equipment between ingredients.

Livestock Production

Essential Factors

A fifth essential factor is added for livestock centers—waste disposal. Requirements, regulations, public demand, and simply good livestock management practices have made the management of livestock wastes a subject for major farmstead planning decisions.

Water is essential for livestock. Studies have shown that optimum production requires adequate water and that cool water is better than warm in hot weather. Management practices also often require water for cleaning (pens, milking equipment), sanitation spraying, waste removal, and summer cooling of animals or ventilation air.

Drainage is listed after "water" only because, while it is difficult to overcome a lack of water, it is usually possible to improve, and often possible to correct, drainage. When engineers discuss livestock production or farmsteads, no subject is raised as consistently, as soon, and as fervently as "drainage". Poor drainage has caused more problems, destroyed more otherwise successful layouts, and frustrated more developments than any other factor. Even many livestock waste management problems relate directly to drainage.

Generally, locate livestock facilities on high ground—don't build in a hole. Free fall below a livestock center permits gravity drainage of rain, snow melt, and subsurface water around foundations and pits, and even some gravity waste handling.

Production Volume of a major livestock enterprise affects, and is affected by, the whole farm and all operations. Utilities, feed, machinery, traffic, nuisances, space—all become more demanding with size increases.

Off-Farm Factors such as odors, dust, noise, and possible pollution by livestock wastes can affect your neighbors as well as your family. Neighbors can change from sympathetic farmers to less tolerant sub-division dwellers. While accurate long-range predictions may be impossible, observe current trends. Investigate zoning law developments with government offices, and avoid foreseeable major impacts on off-farm areas.

Most nuisances are air- or water-borne; locate livestock and waste facilities downwind from off-farm living centers as well as from your own, and control runoff before it leaves your farm. It is usually easier in the long run to avoid complaints than to adequately respond to one already raised.

Wastes from a large modern livestock center can concentrate in such a small area that their handling and disposal become almost an "activity center". Waste management has become a critical factor because regulations can prohibit some developments, require or prohibit certain management practices, and constrain some planning decisions.

Planning Factors

Distance factors for a livestock unit depend on the kind of animal; its age, size, or maturity; the size of the unit; the amount of care required; and facilities factors such as housing in closed or open buildings, feeding in feedlots, or product processing in a milkhouse or egg room.

Table 1 compares different classes of livestock by their weight equivalents for distance planning. Total weight is a partial measure of amounts of feed and manure to be handled, amount of ventilation air, and approximate building size. Table 2 suggests minimum distances livestock centers should be removed from the family living center. The numbers in the tables are guides only. They are included to help you understand, rather than to suggest absolute values.

Animals in a closed, fan-ventilated building tend to create less nuisance than, for example, 200 feeder steers in a dirt lot.

Baby animals tend to need more care and create less nuisance than feeder or mature animals. They are also more apt to be in closed buildings.

Some parts of some livestock centers create much less nuisance than others. The milkhouse of a dairy center has little effect on family living except the visits of the bulk milk truck.

Table 411-1. Enterprise sizes for livestock.

These numbers do not accurately measure the effect of enterprise size on either management or location, but do indicate approximately equivalent weights of different kinds of animals.

No. Animal Units	Maximum No. of Different Animals			
	1000# Beef	200# Hogs	1500# Dairy Cows	4# Hens
1 to 20	20	100	13	5,000
20 to 75	75	375	50	18,700
75 to 500	500	2,500	330	125,000

Table 411-2. Zones for livestock enterprises.

Consider the number of livestock and their size when planning a farmstead.

No. Animal Units	Farmstead Zone	Minimum Distance From House For Nearest Livestock Buildings
1 to 20	2 or 3	100'
20 to 75	3	200'
75 to 500*	4	300'

* Over 500 animal units may overwhelm other farmstead components. Consider a separate center isolated as far as practical from any residence.

Topography determines overall drainage patterns. It can restrict the space available for a large center, and can affect access routes and convenience to utilities and other farmstead centers.

After reasonable space needs are determined for the facility being planned, double them—allow for twice the space needed soon. Extra space between buildings helps prevent fire spread, may increase access, and allows future changes without over crowding.

Plan adequate space for livestock-related facilities: corral, hospital unit, access road, feed center, and processing and storage buildings (milkhouse, egg-handling room).

A sloped area is usually best for a livestock center. Slopes of 2%-6% will drain, but not cause erosion in many soils. A south slope dries better, and is especially preferred for unpaved lots. Earth moving can usually create desirable slopes and graded-up areas for buildings.

Planning Services

Drives and Parking

Criteria for developing and maintaining drives include: surface for year-round use; drainage to help maintain the surface and control runoff water; space for vehicles to travel, maneuver, and park; space for storing plowed snow; convenience for visitors and farm family; and safety for drivers and children.

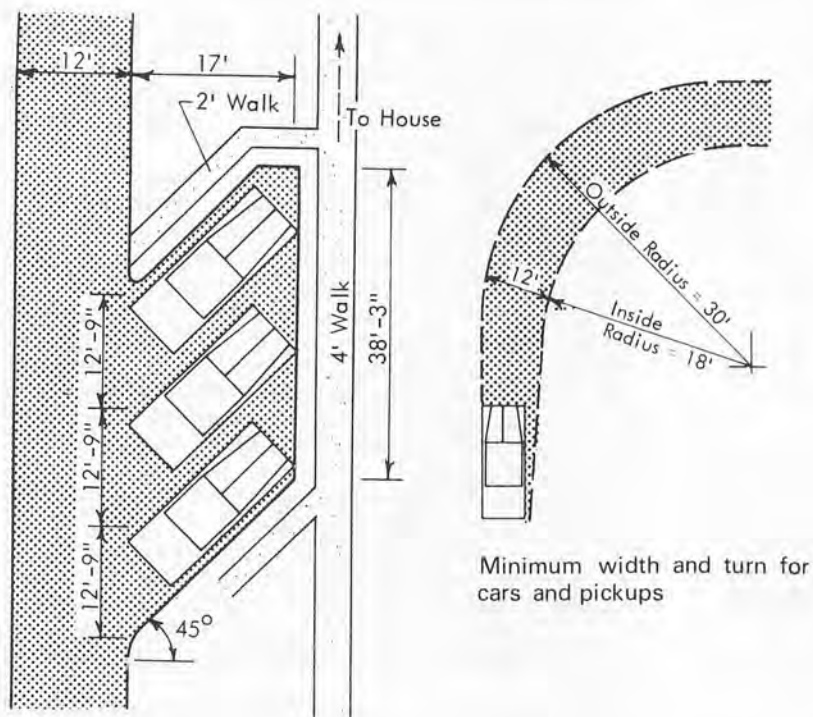
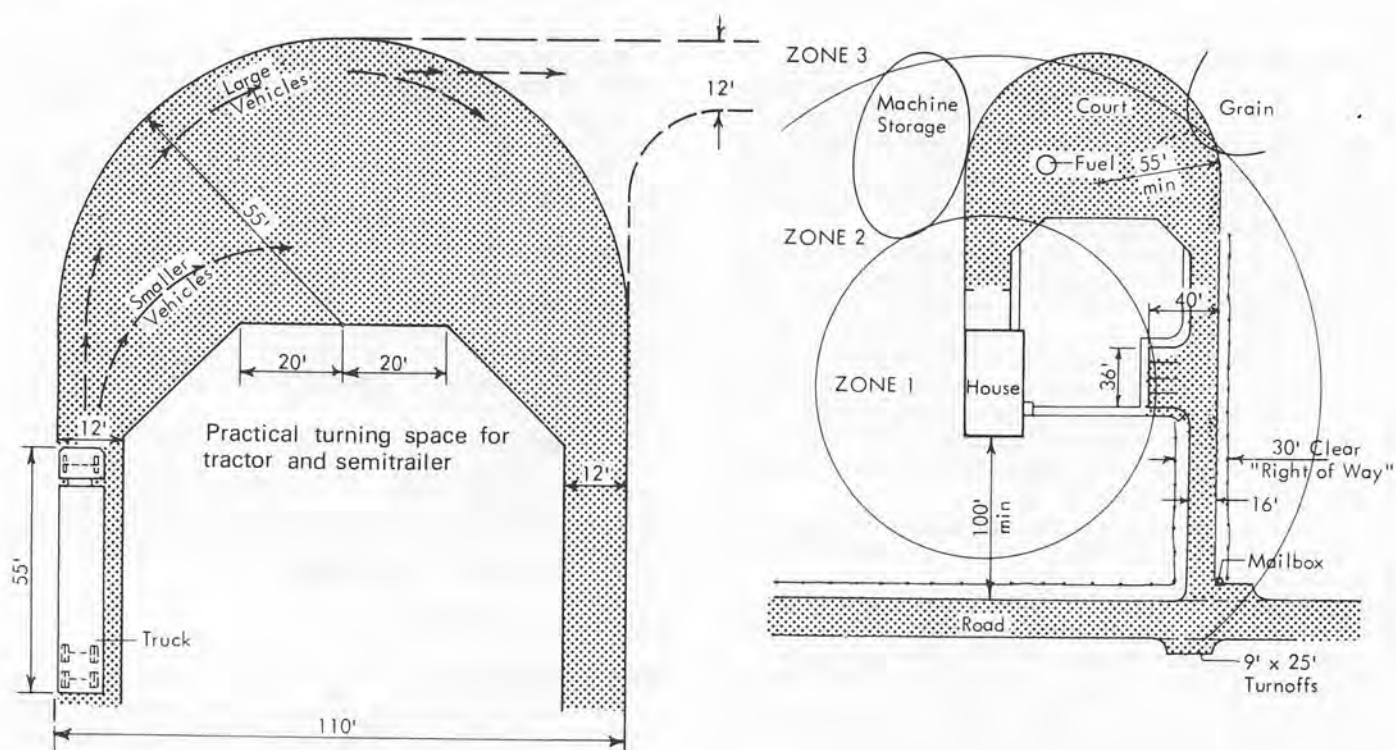
Entrance Drive from Road to Farmstead

A single entrance drive is usually desirable for traffic control and so vehicles can be readily observed from the house and farmstead. Exceptions include a second drive to a major remote unit, such as a large livestock center, or to a second house near the farmstead.

Enter the drive from the road either at the top of a hill, or far enough from the top for safe visibility. A fast moving car or truck needs time and distance to avoid a slower moving farm vehicle entering the drive. Provide turn-offs next to the road, to permit a driver to wait safely while a large vehicle clears the drive, or to wait for opposing vehicles before turning. The mailbox is usually at one of the turn-offs. Locate a gate to the main drive at least 40', and preferably 60', from the road, so cars and trucks can stop off the road while the gate is opened.

Maintain the drive surface about 16' wide, with at least 7' of additional clearance on each side. The extra width allows for large overhanging equipment and provides for snow storage; drainage along the drive can be within this "right of way". Make the drive straight, or with gentle curves, for large vehicles. Surface walks along drives and to parking areas.

Usually the house is the first building approached along the drive. Family guest traffic can be kept out of the courtyard, observation of traffic can be maintained, and landscaping can both enhance family living and provide an attractive welcome to visitors.



Maneuvering farm equipment. These measurements are from very limited field data.

Implement	180° Turn feet
1 hay wagon	48'
2 hay wagons	68'
manure spreader	34'
grain wagon	34'
forage harvester	48'
forage harvester and forage box	61'

Fig 411-6. Overall dimensions for drives and parking.

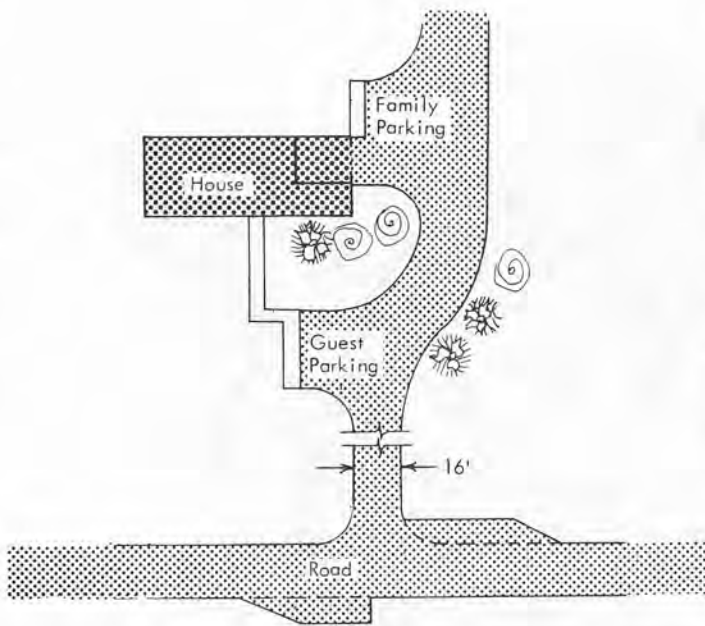


Fig 411-7. Example of guest parking.

Family parking and the farm court are screened to encourage visitors to use the guest entrance.

Guest Parking

Provide for three types of visitors: encourage family guests to use the guest entrance to the house; encourage business visitors to park near the farm office; and encourage heavy business traffic—delivery and shipping trucks—to proceed to the court.

Invite visitors to your guest entrance by providing obvious parking for 3 to 5 cars and a direct walkway to the door. Screen the route to the service entrance and farm buildings with plantings.

Court

The farmstead court is usually an extension of the main drive. Plan for parking and maneuvering machines and trucks.

Provide good drainage, for year-round use and convenience. Provide area lighting for safety, convenience, and security.

A common layout provides a loop drive connecting the various farmstead activity centers, leaving an open space in the center for overflow parking.

A U-drive and court—twin entrance drives—are not recommended.

Zone planning and the resulting spaces between activity centers open up the court by placing buildings some distance apart. More surfaced drive may be needed, but access to buildings, space to ma-

neuver large vehicles, fire safety, and room for expanding an enterprise are all improved.

Branch Drives

Branch drives off the entrance drive may serve guest parking, office and visitor parking, family garage and family parking, and a building not requiring access by large vehicles.

A straight drive can be as little as 8' wide. Additional width is desirable for curves, pedestrians walking beside parked cars, and for occasional parking. Twelve feet wide is desirable for sharp curves, and for maneuvering vehicles in and out of parking or garages. Lay out curves to a 18' inside radius, 30' outside.

Wind and Snow Control

Any time wind speed is reduced, snow or dust settles out. Therefore, any effort to control wind affects snow, and vice versa.

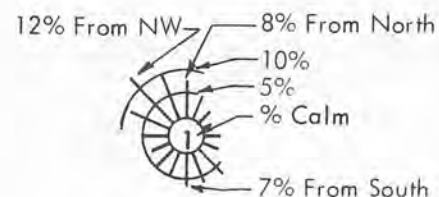
In the north central states, tree windbreaks (shelterbelts) are used to reduce wind velocities around farmsteads; to catch a major part of heavy snows outside the farmstead area.

In areas that experience cold and windy winters with lots of snow, large farmstead windbreaks are planted and carefully maintained. Generally 7 rows of trees are planted along the west and north sides of the farmstead, although 12 rows are not uncommon; 2 to 4 rows are usually planted along the east and south. Much space is taken up by the trees and the downwind snow catch area.

Farther east, as in Indiana and Michigan, planted windbreaks are rare, but windbreak fences are common around farmsteads and livestock drylots.

Wind Speed

A wind rose is a picture of prevailing wind directions.



Des Moines, Iowa
January

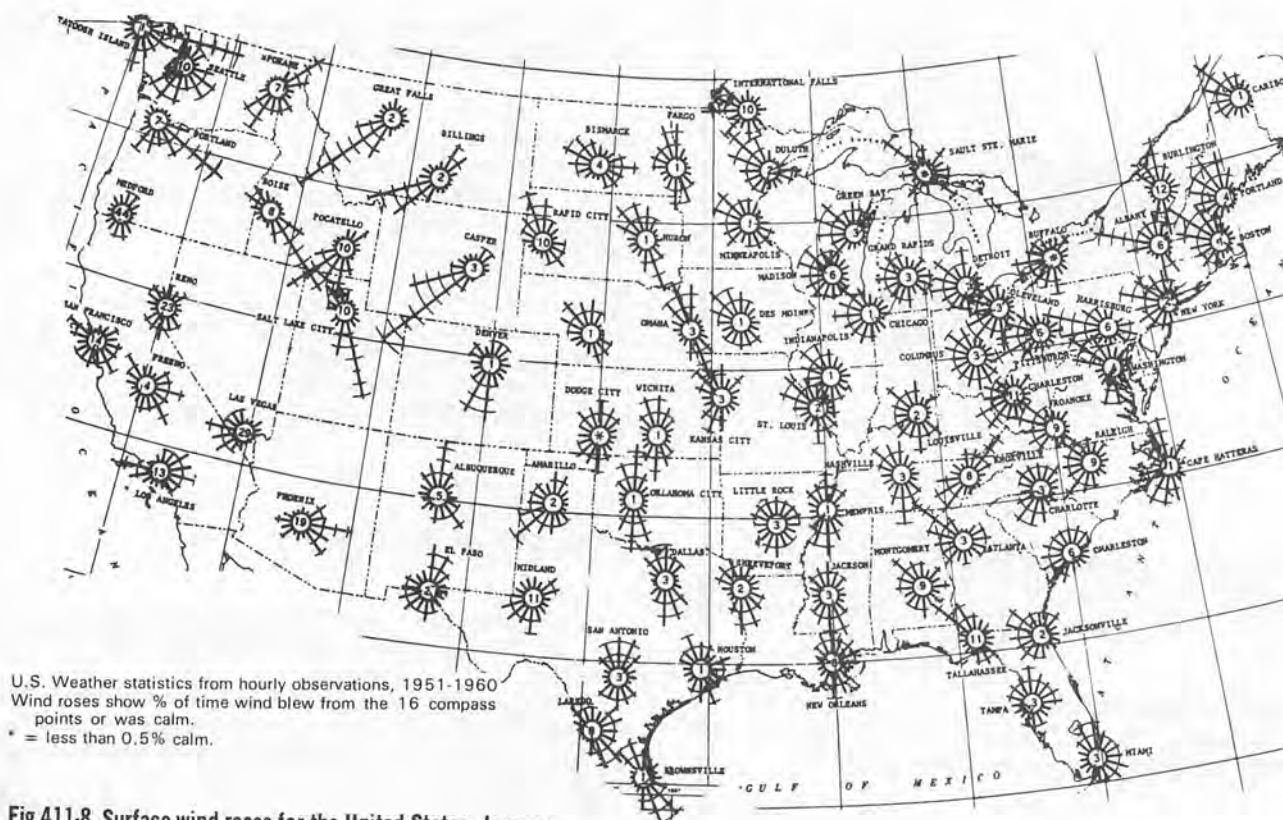


Fig 411-8. Surface wind roses for the United States, January.



Fig 411-9. Surface wind roses for the United States, July.

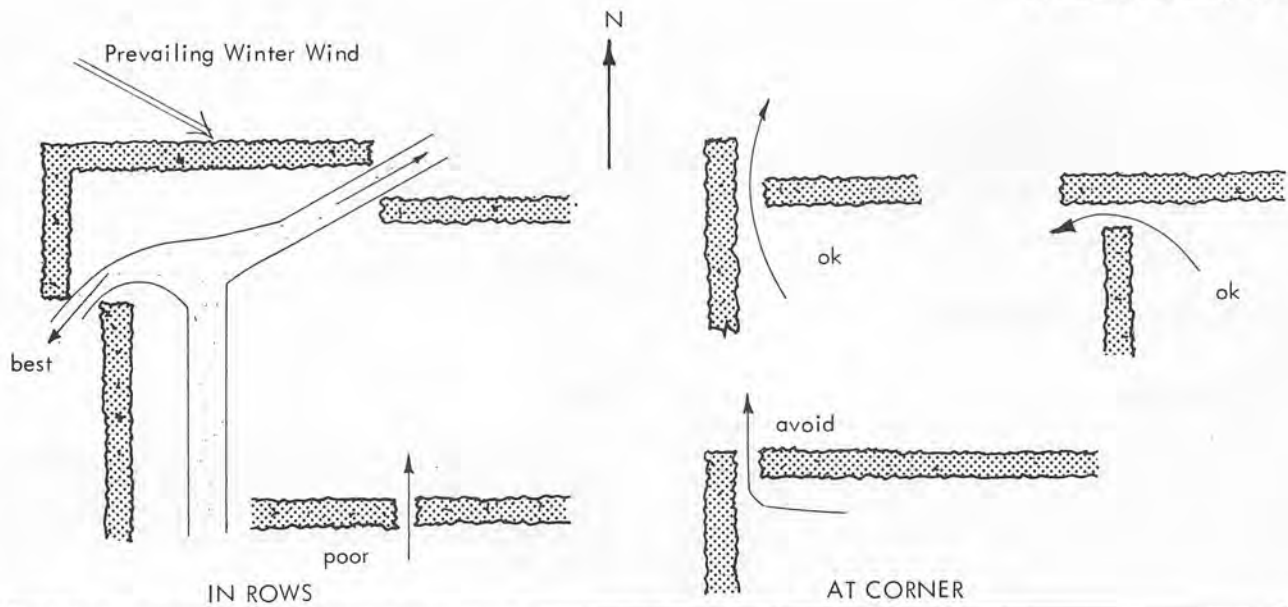


Fig 411-10. Planting rows to permit vehicle traffic—and to prevent wind-tunneling in the winter.

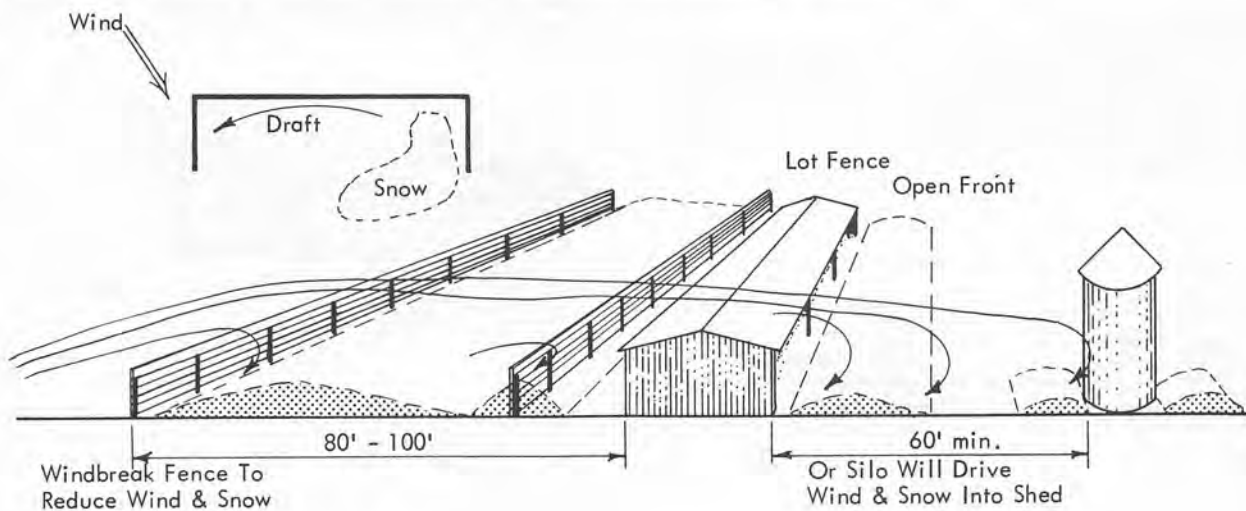


Fig 411-11. Snow and wind in an open front shed.

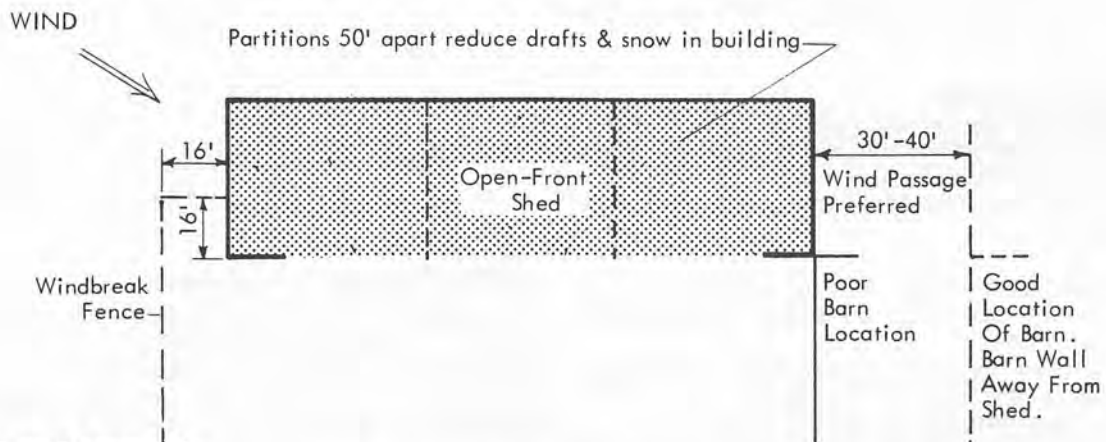


Fig 411-12. Protecting open sheds.

Close end bays, add partitions and windbreaks. With shed next to barn, wind is funneled into shed.

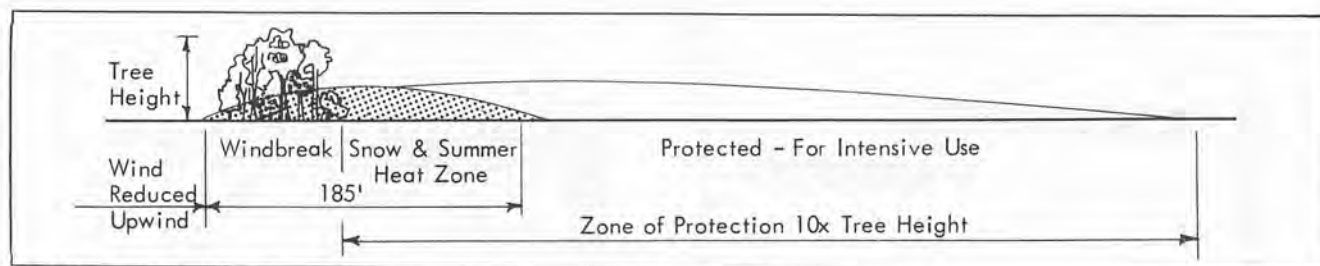


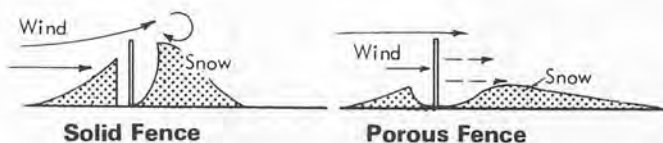
Fig 411-13. Protection from a tree windbreak.

Tree Windbreaks

A good tree windbreak reduces wind velocities 5 to 10 tree heights upwind, and 10 to 30 tree heights downwind. For extreme wind and snow conditions plant tall and short trees, evergreens, and shrubs. Such a tree windbreak is 125'-150' wide. Plant rows 15'-20' apart to permit cultivating for weed control. Contact your county agricultural agent for planting and species recommendations.

Windbreak Fences

A solid fence provides good wind protection for a short distance downwind. A fence only about 80% solid reduces wind speed for a greater distance, and tends to spread out a snowdrift for faster melting.



A 10' high slotted windbreak fence (or trees) on a 4' high ridge can protect a 200' wide feedlot, if the lot slopes away from the windbreak 6%-8%.

Positioning Windbreaks

Locate buildings, feedlots, and equipment within the area of wind protection, but beyond the snow catch zone. In summer, when wind cooling is desirable, avoid the sheltered area close to a large windbreak.

Protect open sheds from wind and snow:

- Don't build an open shed close to a barn or silo.
- Install windbreak fence at ends of the building to form a 16'x16' swirl chamber.
- Install solid partitions about 50' apart.
- Close in part of the front wall, about one bay at each end of a long building.

Sun

During cold weather, sun heat warms buildings and helps dry surfaces. During hot weather, control or screen solar energy out of buildings with roof overhangs, awnings, trees, reflective roof surfaces, etc.

Solar Orientation

- It is easier to screen out solar heat in the summer with long buildings oriented E-W. The east and west walls are sun-heated a relatively short

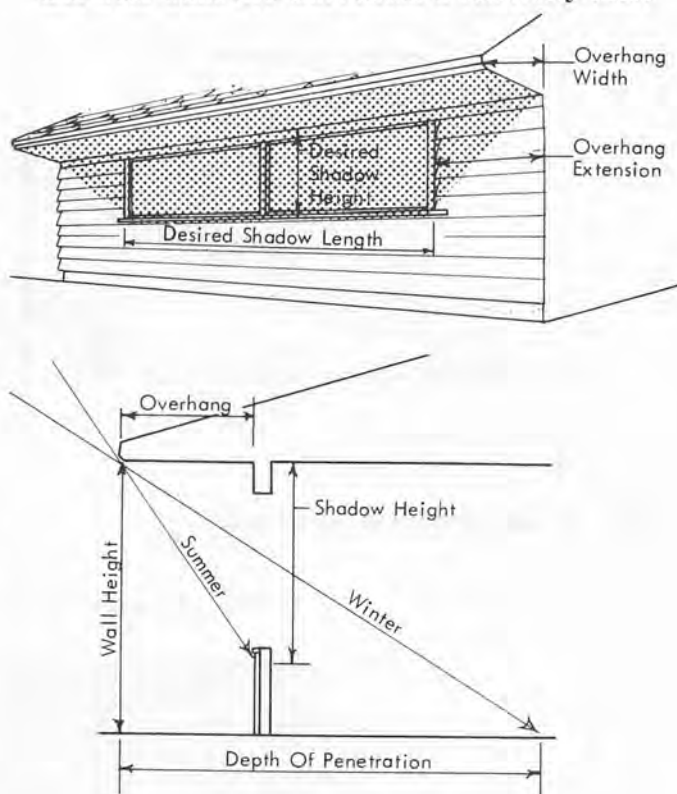


Fig 411-14. Sun angle, winter and summer.

The upper part of the wall "sees" no sun from Apr 21 to Aug 21 between 9:30 a.m. and 2:30 p.m. with the specified overhang and overhang extension. Overhang extension prevents sun shining under end of overhang and onto the desired shadow area. Sun penetrates at least to Depth of Penetration, P, from November 21 to January 21.

time, and because of low sun angle in the morning and evening, are difficult to shade. The south wall can be shaded with an overhang. The sun will not melt snow along the north wall.

- Total sun heat on building walls in the winter is greater for buildings oriented E-W.
- N-S oriented feed bunks thaw and dry faster than E-W oriented bunks—avoid shading by silos or buildings.
- Shades oriented N-S in feedlots remain drier than E-W oriented shades.
- Shade from silos or buildings can increase snow, ice, and freeze buildup around feed bunks, in silos, and on roads or traffic ways.

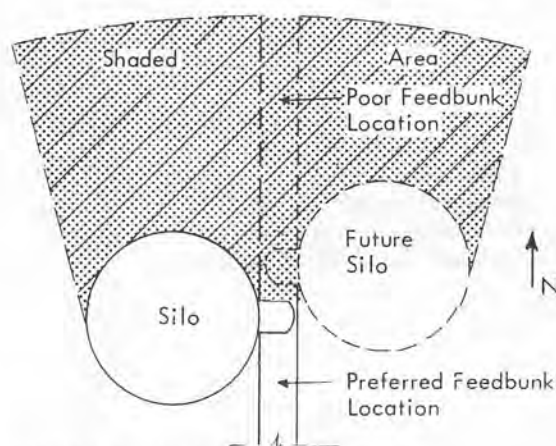


Fig. 411-15. Silo shadows on a feedbunk.

Feeding areas south of the silos are exposed for sun drying, but a large area north of the silos is shaded during the warmer parts of winter days.

Table 411-3. Sun effects on south-facing wall.

Overhang width and extension for desired shading between Apr 21 and Aug 21. Wall height for desired sun penetration between Nov 21 and Jan 21.

Height of Shadow, ft	Degrees N. Latitude							
	24°	28°	32°	36°	40°*	44°	48°	52°
Width of Overhang, ft								
3'	0.6'	0.9'	1.1'	1.3'	1.6'	1.9'	2.9'	2.5'
4'	0.9	1.1	1.5	1.8	2.1	2.5	2.9	3.3
5'	1.1	1.4	1.8	2.2	2.7(1)	3.1	3.6	4.2
6'	1.3	1.7	2.2	2.7	3.2	3.7	4.4	5.0
8'	1.7	2.3	2.9	3.6	4.2	5.0	5.8	6.7
10'	2.1	2.9	3.6	4.5	5.3	6.2	7.3	8.4
12'	2.6	3.4	4.4	5.3	6.4	7.5	8.7	10.1
Overhang Extension, ft								
3'	3.0'	2.8'	2.6'	2.7'	2.8'	2.9'	2.9'	3.2'
4'	4.0	3.8	3.5	3.7	3.8	3.8	3.9	4.2
5'	5.0	4.7	4.4	4.6	4.7(2)	4.8	4.9	4.3
6'	6.0	5.6	5.3	5.5	5.6	5.8	5.9	6.3
8'	8.0	7.5	7.0	7.3	7.5	7.7	7.9	8.4
10'	10.0	9.4	8.8	9.1	9.4	9.6	9.8	10.5
12'	12.0	11.3	10.5	11.0	11.3	11.5	11.8	12.7
Depth of Penetration, ft								
Wall Height								
6'	5.8'	6.7'	7.7'	8.9'	10.4'	12.3'	14.9'	18.5'
7'	6.8	7.8	9.0	10.4	12.1	14.4	17.3	21.5
8'	7.7	8.9	10.2	11.9	13.9(3)	16.4	19.8	24.6
9'	8.7	10.0	11.5	13.3	15.6	18.5	22.3	27.7
10'	9.7	11.1	12.8	14.8	17.3	20.5	24.8	30.8
12'	11.6	13.3	15.4	17.8	20.8	24.6	29.7	36.9
14'	13.5	15.5	17.9	20.8	24.2	28.7	34.7	43.1

* Examples for 40° N. Latitude (See Fig 28)

- 1) 5' shadow height requires 2.7' wide overhang.
- 2) 4.7' wide overhang extensions to the east and west, for summer shade Apr 21 to Aug 21.
- 3) Winter sun will penetrate 13.9' behind an overhang 8' above floor level.

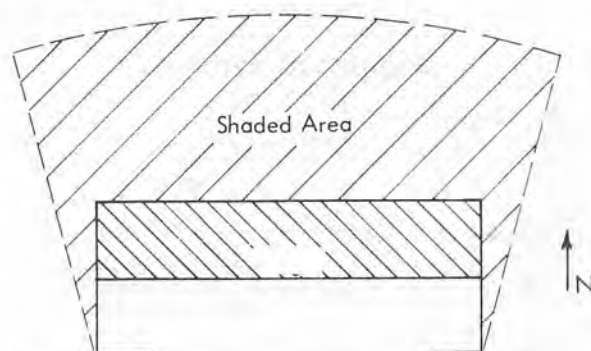


Fig 411-16. Shadows north, and inside, of buildings.

Large opening in building wall permits sunlight to enter building. Areas toward back of building, and to the north, will not thaw or dry rapidly because they are shaded during the warmer parts of the day.

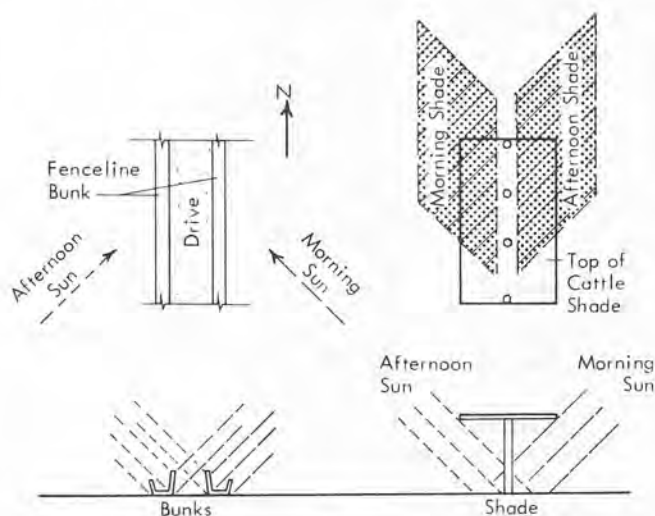
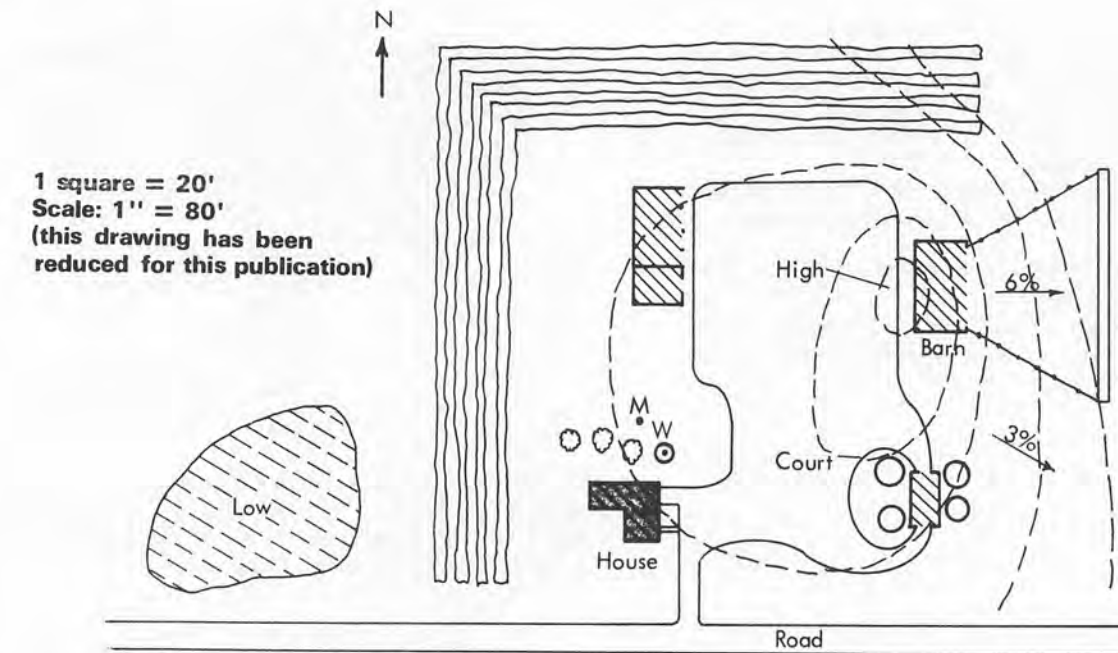
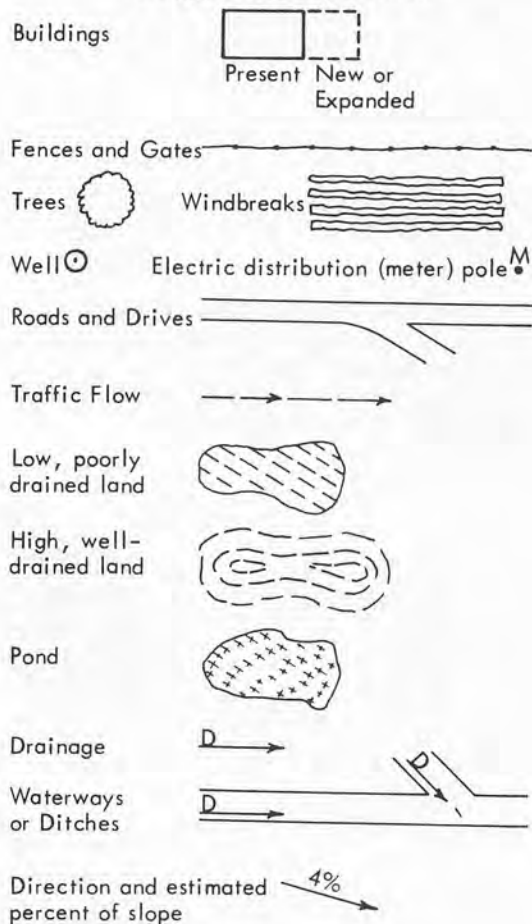


Fig. 411-17. Orient fenceline bunks and cattle shades N-S so sun shines on each side for better drying.



Suggested Symbols



If elevations have been measured, lightly pencil the elevation at important points. Pencil contour lines on the map by estimating lines of equal elevation.

Prepare your map on squared paper; $\frac{1}{4}$ " squares, with one square equal to perhaps 10' or 20'. Be as accurate as possible; use a straight edge (ruler, T-square, or draftsman's triangle) for straight lines. Start with light pencil lines that can easily be erased. Use symbols where possible to reduce the amount of lettering needed.

One way of developing a farmstead map is to use a grid system.

Using a 100' tape measure, lay out a grid system of 100 foot squares over the entire farmstead site. Place a stake at each corner of the squares. Label the stake with a number and a letter to show its position. Locate all drives, buildings, water, power, or other facilities within the grid system. For example, a barn has its SW corner at 4 + 40 and d + 30.

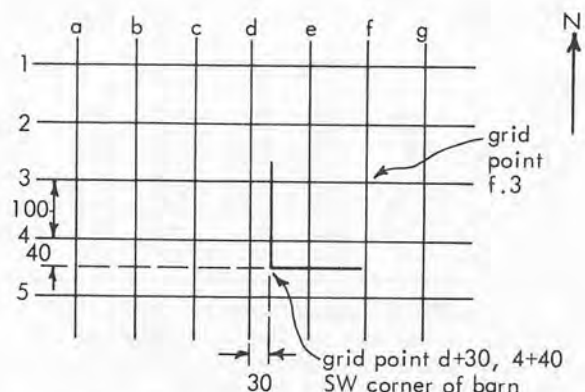


Fig 411-19. Dimension grid for farmstead map.

Fig 411-18. Farmstead map.

Symbols typically used to show physical features on a farmstead plan.

CHAPTER 412. ENGINEERING ECONOMICS*

Introduction

In planning engineering projects, it is often necessary to consider alternatives on the basis of economy. Compare them on an equivalent basis so the alternatives give either identical results or differences expressed in terms of money.

Money has a time value because of interest. Payments that differ in magnitude can be equivalent if they are made on different dates.

If \$200 are put in a sock, at the end of 2 years there will still be a cash value of \$200. If the \$200 are deposited at 8% interest compounded annually, the cash value will be $\$200(1 + 0.08)^2 = \$233.28$ after 2 years. Therefore, \$200 today is equivalent to \$233.28 two years later at 8% earnings compounded annually. Similarly, to have \$200 in 2 years, deposit $\$200/(1 + 0.08)^2 = \$171.46$ at 8% interest now.

Money that is borrowed to finance an alternative has interest costs that are direct expenses against the alternative. There is also an expense charged for using available funds, whether or not they are currently invested, for the interest income that could have been earned. For economic analysis, the cost of using funds is the same whether the money is borrowed or available.

Four steps are needed to solve an engineering economics problem:

1. Define the alternatives.
 - Select the plan, process, or method and prepare plans with sufficient detail to estimate costs. The alternatives may be remodeling an existing building versus building a new one, for example.
 - Select materials: low cost, but shorter life, materials versus more expensive, longer life materials.
2. Reduce alternatives to consistent time and money differences considering:
 - Initial investment, the estimated cost of each alternative.
 - Operating costs, the annual expense of (abbreviated DIRT): depreciation, interest, repairs and maintenance, taxes, and insurance. Other items such as fuel and labor are considered when necessary.
 - Operating returns such as the fertilizer value received from manure.
 - Time phasing of monetary expenditures and returns.
3. Assume an interest rate.
 - It is needed to make alternative money-time series comparable.
 - The rate is the cost of borrowing money.

4. Reduce alternatives to a comparable basis with one of the following methods: annual cost, present worth, or prospective rate of return on extra investment.

Notation

- D = annual depreciation
- V_a = value of asset when acquired
- V_p = book or present value of asset
- V_r = replacement value of asset
- V_s = estimated salvage value
- n = estimated life in years, also number of interest periods
- x = number of years or interest periods the asset has been utilized to date
- i = interest rate per interest period
- I = total interest due
- P = a present sum of money
- F = future sum of money, n interest periods from the present date
- R = one of the end-of-period payments in a uniform series over n periods

Interest

Interest is money paid for the use of borrowed money or is money earned from the use of loaned money. Because of interest, a dollar now is worth more than the prospect of a dollar next year.

The interest rate is the ratio between the interest payable at the end of a period of time, usually a year or less, and the money owed at the beginning of that period. Borrowers want to minimize the interest rate; lenders want to maximize it. The actual rate is a compromise based on the availability of capital, investment opportunities, and the degree of risk of the loss of capital.

Simple interest

The amount of interest due is based on the initial value of the loan, the interest rate, and how long the loan lasts. It is usually payable at the end of the loan period.

$$I = Pin \quad \text{Eq 412-1}$$

$$F = P(1 + in) \quad \text{Eq 412-2}$$

Compound interest

Interest earned during the first period of the loan is added to the loan, and interest is earned on this new total during the following periods. The amount due at the end of the first period on which the second period's interest will be calculated is:

$$F_1 = P + Pi$$

For the second period the amount due is:

$$F_2 = P + Pi + (P + Pi)i = P(1 + i)^2$$

*This chapter was prepared by Dr. C. O. Cramer, University of Wisconsin.

At the end of the n th year the amount due is:

$$F_n = P(1 + i)^n \quad \text{Eq 412-3}$$

Nominal interest rate

A year is often divided into several interest periods. Interest is earned and compounded during each period. The total interest figure can be quoted as an annual rate and the number of interest periods per year can be given. For example, interest at 4% per half year can be given as 8% compounded semiannually. The nominal interest rate is 8%. For \$1000:

$$F_{6 \text{ mo.}} = P + Pi = \$1000 + (\$1000 \times .04) \\ = \$1000 + \$40 = \$1040$$

$$F_{1 \text{ yr}} = \$1040 + (\$1040 \times .04) \\ = \$1040 + \$41.60 = \$1081.60$$

Effective interest rate

The way the interest rate is quoted affects the actual or effective rate. Comparing the future value of \$1000 compounded at 8% annually (\$1080) and semiannually (\$1081.60):

- For \$1000 at 8% compounded annually:

Effective interest rate =

$$\frac{F - P}{P} = \frac{\$1080 - \$1000}{\$1000} = .08 = 8\%$$

- For \$1000 at 8% compounded semiannually:

Effective interest rate =

$$\frac{F - P}{P} = \frac{\$1081.60 - \$1000}{\$1000} = .0816 = 8.16\%$$

Compound Interest Factors

Cash flow is translated to a particular time by determining either its present or its future worth. A present-worth calculation converts a single future sum or a series of future values to an equivalent amount at an earlier date. This date is usually, but not necessarily, the present. Future-worth calculations convert present or earlier values to an equivalent amount at a later date.

Equivalent values can be determined by calculating the compound amount of each sum for each period. Avoid this tedious task with the following compound interest factors, which can be selected from a table or easily computed with a hand calculator.

There are two types of factors; one converts a single amount to a present or future value. The other converts a series of amounts.

Single payment Compound Amount Factor (CAF)

If a single sum is deposited at compound interest, it grows at the interest rate to a future sum. Calculate the final sum (F) in the fund based on the deposit (or principal, P) and the interest rate, i , and the number of interest periods, n .

$$CAF = (1 + i)^n \quad \text{Eq 412-4}$$

$$F = P(CAF) \quad \text{Same as Eq 412-3}$$

If the future sum, F , is known, the size of the needed deposit, or principal, is:

$$P = F/(CAF) \quad \text{Eq 412-5}$$

Eq 412-5 is often expressed as $P = F(PWF)$, where PWF is the Present Worth Factor, in many interest tables, and is simply the reciprocal of the CAF.

Series Compound Amount Factor (SCAF)

If a uniform sum, R , is deposited regularly over n periods, and the accumulating deposits earn compound interest at the rate i , calculate the future sum, F , with the SCAF.

$$SCAF = [(1 + i)^n - 1]/i \quad \text{Eq 412-6}$$

$$F = R(SCAF) \quad \text{Eq 412-7}$$

This future sum, F , derived from a series of uniform payments is called a sinking fund.

To find the size of the regular payment to develop a desired size of fund:

$$R = F/(SCAF) \quad \text{Eq 412-8}$$

Eq 412-8 is often expressed as $R = F(SFF)$, where SFF is the Sinking Fund Factor in many interest tables and is the reciprocal of the SCAF.

Series Present Worth Factor (SPWF)

With a sinking fund, interest is paid on deposited regular payments. Present worth is similar to a house or auto mortgage, where borrowed principal with interest is paid by a series of uniform payments. The loan is made on, for instance, July 1, and the first payment is made on August 1. Interest is computed for the amount of the loan for the month of July and is subtracted from the payment; the remaining amount of the August 1 payment is deducted from the principal. Interest is paid in August on the reduced principal. Because the principal decreases, the amount of interest due decreases, and the portion of each regular and uniform payment going to principal increases.

Use the SPWF to find the amount of principal, P , a payment of R will reduce to zero in n periods at interest i .

$$SPWF = [(1 + i)^n - 1]/i(1 + i)^n \quad \text{Eq 412-9}$$

$$P = R(SPWF) \quad \text{Eq 412-10}$$

To find the needed payment, R , to reduce the principal, P :

$$R = P/(SPWF) \quad \text{Eq 412-11}$$

Eq 412-11 is often expressed as $R = P(CRF)$, using the Capital Recovery Factor which is the reciprocal of SPWF.

Depreciation

Depreciation is the decrease in value of an asset due to physical wearout, obsolescence, or depletion of resources. Most agricultural assets decrease in value as they get older. The change in worth of an asset is accounted for by depreciation charges made during its productive life.

Depreciation and maintenance are occasionally confused since they both are concerned with physical deterioration resulting from age and service.

Maintenance is keeping a property in reasonably good condition; for example, painting a building or replacing a wornout roof. Repair includes the replacing or mending of broken parts. Both maintenance and repair are operating expenses. Occasionally extensive repairs restore value lost through depreciation; consider such expenditures as new investment.

Depreciation is the loss in value that occurs despite prudent maintenance and repairs. Consider depreciation in an economy study for two reasons: to provide for recovering capital invested in physical assets, and to enable the depreciation costs to be charged to production costs.

Monetary depreciation, a change in price levels, is a subtle cause of depreciation. Usual accounting practices relate depreciation to an asset's original cost, not to its replacement. If construction costs rise during a building's life, a comparable replacement is more expensive. Capital recovery will not provide an adequate replacement for the worn out asset. Because invested capital depreciates, not the asset itself, the effect is difficult to estimate.

The life of an asset must be estimated to determine depreciation or make an economic comparison of alternatives. The life selected is affected by its intended use. For tax purposes, the shortest allowable life is generally most advantageous. For an engineering comparison, base the life on the best information available on the history of similar assets and the intensity of use. Includes salvage values for any assets with significant value at retirement.

Depreciation Accounting Methods and Present Value

In making depreciation studies, consider a charge for depreciation as a series of payments to a specific fund to replace the asset. Where the charge is used for tax purposes, the actual money is handled as working capital. However, in an engineering economy study, assign the depreciation charge to each alternative to recover the initial cost with interest.

The book, or present value, of the asset is the original cost minus the accumulated depreciation charges. Book value can be very different from market or sale value.

Straight line method

This is the simplest and most widely used depreciation method. The annual depreciation is constant; the cost-less-salvage value uniformly decreases over the prospective life. The disadvantages are:

- Does not discount future services, which are less valuable as the service becomes more remote.

- Is not the most favorable for tax purposes.
- Ignores the actual increase in rate of value loss toward the end of useful life.

To compute annual straight line depreciation:

$$D = [V_a - V_s] / n \quad \text{Eq 412-12}$$

Present value of an asset using straight line depreciation is:

$$V_p = V_a - \frac{x}{n} (V_a - V_s) \quad \text{Eq 412-13}$$

Sinking fund method

An imaginary sinking fund is built by uniform end-of-year annual deposits throughout the life of the asset. Assume the deposits draw interest and build a fund equal to the asset's cost minus its estimated salvage value at the end of its estimated life.

The slow early loss and later rapid loss are more consistent with the real loss in value. However, the method usually writes off costs too slowly for favorable income tax deductions.

The depreciation expense in any year is the sinking fund deposit plus the interest on the imaginary accumulated fund.

$$\begin{aligned} D &= (V_a - V_s) \frac{i}{(1+i)^n - 1} \\ &+ i(V_a - V_s) \frac{(1+i)^{x-1} - 1}{(1+i)^n - 1} \\ &= (V_a - V_s) \frac{i(1+i)^{x-1}}{(1+i)^n - 1} \end{aligned} \quad \text{Eq 412-14}$$

or by interest tables

$$D = (V_a - V_s)(SFF_n)[1 + i(SCAF_{x-1})] \quad \text{Eq 412-15}$$

The present value at any time is the first cost of the asset minus the current amount accumulated in the imaginary (sinking) fund.

The present value at the end of x years of an asset with a life of n years using the sinking fund method is:

$$V_p = V_a - (V_a - V_s) \frac{(1+i)^x - 1}{(1+i)^n - 1} \quad \text{Eq 412-16}$$

$$= V_a - (V_a - V_s)(SFF_n)(SCAF_x) \quad \text{Eq 412-17}$$

Declining balance method

The annual depreciation charge is a fixed percentage of the declining book value. If the fixed percentage is 2.5 times the straight line rate based on average service life, about 50% of the cost of the asset is written off during the first 25% of its life.

This method gives rapid depreciation write-off for income tax purposes. It is more difficult to calculate than straight line, because the depreciation charges are different each year. Salvage values complicate this method and are neglected here.

Calculate depreciation at year x by:

$$D = fV_a(1 - f)^{x-1} \quad \text{Eq 412-18}$$

where f = fixed percentage depreciation charge
(use 2.5 times straight line rate)
= 2.5/years expected life.

The present asset value at the end of x years is:

$$V_p = V_a(1 - f)^x \quad \text{Eq 412-19}$$

Sum of digits method

This method also gives larger depreciation during the early years of ownership. The advantages and disadvantages are similar to the declining balance method. The annual charge is the ratio of the sum of the digits representing the remaining years of life ($n - x + 1$) to the sum of the digits for the entire life ($1 + 2 + 3 + \dots + n$) multiplied by the difference between acquired and salvage values ($V_a - V_s$).

$$D = \frac{n - x + 1}{1 + 2 + 3 + \dots + n} (V_a - V_s) \\ = \frac{2(n - x + 1)}{n(n + 1)} (V_a - V_s) \quad \text{Eq 412-20}$$

$$V_p = \frac{2[1 + 2 + \dots + (n - x)]}{n(n + 1)} (V_a - V_s) + V_s \quad \text{Eq 412-21}$$

Example—depreciation and present value calculations

Data: A dairy barn constructed in 1963 cost \$40,000. Its probable useful life is 25 years with zero salvage value. Assume construction costs have increased 5%/yr. Use 8% interest rate.

Determine:

1. Annual depreciation based on cost new in 1963.
2. Present value of the barn at the end of 1975 (12 years old) based on replacement cost in 1975.

Solution:

- Straight line depreciation method:

$$D = \frac{V_a}{n} = \frac{\$40,000}{25 \text{ years}} = \$1,600/\text{year}$$

Replacement Cost (V_r), 5% increase

$$V_r = (V_a - V_s)(CAF_{12}) = (\$40,000)(1.796) = \$71,840$$

Present Value (V_p) based on Replacement Cost (V_r)

$$V_p = V_r(1 - \frac{x}{n}) = \$71,840(1 - \frac{12}{25}) = \$37,356.80$$

- Sinking fund method:

$$D_1 = V_a \frac{i(1 + i)^{x-1}}{(1 + i)^n - 1} = \$40,000 \frac{(0.08)(1.08)^0}{(1.08)^{25} - 1} \\ = \$40,000 \frac{(0.08)(1)}{6.848 - 1} = \$547.20$$

$$D_{12} = \$40,000 \frac{(0.08)(1.08)^{11}}{(1.08)^{25} - 1} = \$1,275.84$$

Or use the interest tables.

$$D_1 = (V_a - V_s)/(SCAF_n) = \$40,000/73.106 = \$547.15$$

$$D_{12} = (V_a - V_s)[1 + i(SCAF_{x-1})]/SCAF_n \\ = \$40,000[1 + 0.08(16.645)]/73.106 = \$1,275.74$$

Present value based on the replacement cost is:

$$V_p = V_r - (V_r - V_s)(SCAF_x)/SCAF_n \\ = \$71,840 - \$71,840(18.977)/73.106 = \$53,191.63$$

- Declining balance method; depreciation rate = $2.5 \times 1/25 = .10$

$$D_1 = fV_a(1 - f)^{x-1} \\ = (.10)\$40,000(1 - .10)^{11} = \$4,000$$

$$D_{12} = (.10)\$40,000(.90)^{11} = \$1,255.24$$

$$V_p = V_r(1 - f)^x = \$71,840(1 - .10)^{12} \\ = \$20,289.74$$

- Sum of digits method:

$$D_1 = \frac{n - x + 1}{1 + 2 + 3 + \dots + n} (V_a - V_s) \\ = \frac{25}{1 + 2 + 3 + \dots + n} (\$40,000)$$

$$= \frac{25}{325} (\$40,000) = \$3,076.92$$

$$D_{12} = \frac{25 - 12 + 1}{325} (\$40,000) = \$1,723.08$$

$$V_p = \frac{2[1 + 2 + \dots + (n - x)]}{n(n + 1)} (V_r - V_s) + V_s \\ = \frac{2(1 + 2 + \dots + 13)}{25 \times 26} (\$71,840) \\ = \frac{2(91)}{25 \times 26} (\$71,840) = \$20,115.20$$

Comparison of Alternatives

Three common methods are used to compare alternatives in engineering economics.

To illustrate these methods, compare two building alternatives. Use 8% interest.

	Building X	Building Y
First cost	\$14,000	\$20,000
Estimated life	15 yr	25 yr
Estimated salvage value	\$0	\$3,000
Annual expenses (DIRTI)	\$800	\$500

Annual cost method

This is the most common method for engineers to compare a nonuniform series of payments. Convert the nonuniform payments to an equivalent uniform series; the uniform payments recover capital investment and annual disbursements.

Calculate the SPWF from Eq 412-9 or select it from interest tables. The amount of the capital recovery (CR) is:

$$CR = [(V_a - V_s) + V_i] / SPWF$$

Building X

$$CR @ 8\% = \$14,000/8.559 = \$1,635.71$$

$$\text{Annual expenses} = 800.00$$

$$\text{Annual cost} = \$2,435.71$$

Building Y

$$CR = \$17,000/10.675 + \$3,000(.08)$$

$$= \$1,592.51 + 240 = \$1,832.51$$

$$\text{Annual expenses} = 500.00$$

$$\text{Annual cost} = \$2,332.51$$

Building Y has a lower annual cost by \$103.20.

Present worth method

A money-time series can be converted to an equivalent single payment at some specified date such as the present. To an investor, the present worth of future payments is the investment needed to secure those future payments with interest at a given rate. The valuation of an asset that represents a right to future net money receipts is a present worth calculation.

Two features of present worth studies are:

- Salvage values are negative payments.
- The same number of years of service are used for each alternative.

Use the least common multiple of the lives and assume renewals with constant first costs, salvage values, lives, and annual disbursements.

For the sample problem, use a 75-year comparison (5-15 yr periods; 3-25 yr periods). Note that the renewals are single events, so PWF is used. Annual expenses are a series, so SPWF is used.

Building Y has a \$1,284.42 advantage in PW.

Compare Present Worth with Annual Cost. Y's annual cost advantage was \$103.20, which when multiplied by the Series Present Worth Factor ($SPWF_{75} = 12.461$) = \$1,285.98, the PW advantage of Building Y (\$1.56 rounding error).

Prospective Rate of Return on Extra Investment

This method compares two money time series by finding the interest rate that makes them equivalent to one another. The objective is to find the interest rate that yields equal annual costs for both alternatives.

In the common situation of comparing two alternatives, one with a lower first cost and higher annual disbursements, the other with a higher first cost and lower annual, this unknown interest rate may be thought of as the prospective rate of return on the excess of investment in the alternative with the higher first cost.

Compare the annual costs at various interest rates for Buildings X and Y (see annual cost method).

	Annual Cost		Annual Cost Advantage	
i	Building X	Building Y	Building X	Building Y
8%	\$2,435.71	\$2,332.51	--	\$103.20
10%	\$2,640.65	\$2,672.89	\$32.24	--

By interpolation, the interest rate that results in equal annual costs is:

$$i = 8\% + \frac{103.20}{103.20 + 32.24} 2\% = 9.5\%$$

Is it worthwhile to spend an extra \$6,000 (difference in first costs) now to save \$300/yr (difference in annual expenses)? The rate of return on this extra investment is 9.5%.

Present worth rather than annual cost can be used in this type of economy study with similar results.

	Building X		Building Y
First cost	\$14,000.00		\$20,000.00
PW of 1st renewal = $(V_a - V_s) / (CAF_n)$	$\$14,000/3.172 = 4,413.62$	$(\$20,000 - \$3,000)/6.848 =$	2,482.48
PW of 2nd renewal = $(V_a - V_s) / (CAF_{2n})$	$\$14,000/10.063 = 1,391.24$	$(\$20,000 - \$3,000)/46.902 =$	362.46
PW of 3rd renewal	$\$14,000/31.920 = 438.60$		
PW of 4th renewal	$\$14,000/101.257 = 138.26$		
PW of annual disbursements = (expenses)($SPWF_{75}$)	$\$800(12.461) = 9,968.80$	$\$500(12.461) =$	6,230.50
PW of all money paid out for 75 years = total of above	\$30,350.52		\$29,075.44
Less PW of final salvage value, V_s/CAF		$-\$3,000/321,205 =$	- 9.34
			\$29,066.10

Table 412-1. Interest tables, compound interest factors.

	2%				3%					4%				5%			
	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor		Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor
n	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$(1+i)^{-n}$	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$(1+i)^{-n}$	n	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$(1+i)^{-n}$	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$(1+i)^{-n}$
1	1.020	1.000	0.980	1.030	1.000	0.971	1.000	1.040	1.000	0.962	1.050	1.000	0.952	1.020	1.000	0.952	1.000
2	1.040	2.020	1.942	1.061	2.030	1.913	1.913	1.082	2.040	1.886	1.103	1.886	1.103	1.040	2.050	1.859	1.039
3	1.061	3.060	2.884	1.093	3.091	2.829	2.829	1.125	3.125	2.775	1.158	2.775	1.158	1.061	3.153	2.723	1.029
4	1.082	4.122	3.808	1.126	4.184	3.717	3.717	1.170	4.246	3.630	1.216	3.630	1.216	1.082	4.310	3.546	1.019
5	1.104	5.204	4.713	1.159	5.309	4.580	4.580	1.217	5.416	4.452	1.276	4.452	1.276	1.104	5.526	4.429	1.009
6	1.126	6.308	5.601	1.194	6.468	5.417	5.417	1.265	6.533	5.242	1.340	5.242	1.340	1.126	6.602	5.076	0.999
7	1.149	7.434	6.472	1.230	7.662	6.230	6.230	1.316	7.698	6.002	1.407	6.002	1.407	1.149	7.742	4.786	0.989
8	1.172	8.583	7.325	1.267	8.892	7.020	7.020	1.369	8.924	6.733	1.477	6.733	1.477	1.172	8.949	4.463	0.979
9	1.195	9.755	8.162	1.305	10.159	7.786	7.786	1.423	10.583	7.435	1.551	7.435	1.551	1.195	11.027	4.129	0.969
10	1.219	10.950	8.983	1.344	11.464	8.530	8.530	1.480	12.006	8.111	1.629	8.111	1.629	1.219	12.578	3.722	0.959
11	1.243	12.169	9.787	1.384	12.808	9.253	9.253	1.539	13.486	8.760	1.710	8.760	1.710	1.243	14.207	3.267	0.949
12	1.268	13.412	10.575	1.426	14.192	9.954	9.954	1.601	15.026	9.385	1.796	9.385	1.796	1.268	15.917	2.757	0.939
13	1.294	14.680	11.348	1.469	15.618	10.635	10.635	1.665	16.527	9.986	1.886	9.986	1.886	1.294	17.713	2.194	0.929
14	1.319	15.974	12.106	1.513	17.086	11.296	11.296	1.732	18.292	10.563	2.079	10.563	2.079	1.319	19.599	1.579	0.919
15	1.346	17.293	12.849	1.588	18.599	11.938	11.938	1.801	20.024	11.118	2.263	11.118	2.263	1.346	21.577	9.880	0.909
16	1.373	18.639	13.578	1.605	20.157	12.561	12.561	1.873	21.825	11.652	2.453	11.652	2.453	1.373	23.657	8.306	0.899
17	1.400	20.012	14.292	1.653	21.762	13.166	13.166	1.948	23.698	12.166	2.649	12.166	2.649	1.400	25.840	7.586	0.889
18	1.428	21.412	14.992	1.702	23.414	13.754	13.754	2.026	25.645	12.659	2.847	12.659	2.847	1.428	28.132	6.723	0.879
19	1.457	22.841	15.678	1.754	25.117	14.334	14.334	2.107	27.671	13.134	3.047	13.134	3.047	1.457	30.539	5.722	0.869
20	1.486	24.297	16.351	1.806	26.770	14.877	14.877	2.191	29.778	13.590	3.253	13.590	3.253	1.486	33.066	4.586	0.859
21	1.516	25.783	17.011	1.860	28.676	15.415	15.415	2.279	31.969	14.029	3.466	14.029	3.466	1.516	35.719	3.321	0.849
22	1.546	27.299	17.658	1.916	30.537	15.937	15.937	2.370	34.248	14.451	3.686	14.451	3.686	1.546	38.505	1.986	0.839
23	1.577	28.845	18.292	1.974	32.453	16.444	16.444	2.465	36.618	14.857	3.912	14.857	3.912	1.577	41.430	5.480	0.829
24	1.608	30.422	18.914	2.033	34.426	16.936	16.936	2.563	39.083	15.247	4.146	15.247	4.146	1.608	44.502	4.000	0.819
25	1.641	32.030	19.523	2.094	36.559	17.413	17.413	2.666	41.646	15.622	4.386	15.622	4.386	1.641	47.727	2.465	0.809
26	1.673	33.671	20.121	2.157	38.553	17.877	17.877	2.772	44.312	15.983	4.632	15.983	4.632	1.673	51.113	1.813	0.799
27	1.707	35.344	20.707	2.221	40.710	18.327	18.327	2.883	47.084	16.330	4.884	16.330	4.884	1.707	54.669	1.053	0.789
28	1.741	37.051	21.281	2.288	42.931	18.764	18.764	2.999	49.968	16.663	5.142	16.663	5.142	1.741	58.403	0.186	0.779
29	1.776	38.792	21.844	2.357	45.219	19.188	19.188	3.119	52.966	16.984	5.406	16.984	5.406	1.776	62.323	0.865	0.769
30	1.811	40.568	22.396	2.427	47.575	19.600	19.600	3.243	56.085	17.292	5.676	17.292	5.676	1.811	66.439	1.516	0.759
31	1.848	42.379	22.938	2.500	50.003	20.000	20.000	3.373	59.338	17.588	5.951	17.588	5.951	1.848	70.761	2.151	0.749
32	1.885	44.227	23.468	2.575	52.503	20.389	20.389	3.508	62.701	17.874	6.232	17.874	6.232	1.885	75.299	2.766	0.739
33	1.922	46.112	23.989	2.652	55.078	20.766	20.766	3.648	66.210	18.148	6.518	18.148	6.518	1.922	80.064	3.361	0.729
34	1.961	48.034	24.499	2.732	57.730	21.132	21.132	3.794	69.858	18.411	6.808	18.411	6.808	1.961	85.067	3.936	0.719
35	2.000	49.994	24.999	2.814	60.462	21.487	21.487	3.946	73.652	18.665	7.100	18.665	7.100	2.000	90.330	4.491	0.709
40	2.208	60.402	27.355	3.262	75.401	23.115	23.115	4.801	95.026	19.793	7.040	19.793	7.040	2.208	120.800	17.159	0.609
45	2.438	71.893	29.990	3.782	92.797	25.519	25.519	5.841	121.720	20.720	8.985	20.720	8.985	2.438	159.700	17.774	0.509
50	2.692	84.579	31.424	4.384	112.790	28.730	28.730	7.107	152.667	22.482	11.467	22.482	11.467	2.692	209.348	18.256	0.409
55	2.972	98.587	33.175	5.082	136.072	26.774	26.774	8.646	191.159	22.109	14.636	22.109	14.636	2.972	272.713	18.633	0.309
60	3.281	114.052	34.761	5.892	163.053	27.676	27.676	10.520	237.991	22.623	18.679	22.623	18.679	3.281	353.584	18.929	0.209
65	3.623	131.126	36.197	6.830	194.333	28.453	28.453	12.799	294.968	23.047	23.840	23.047	23.840	3.623	456.798	19.161	0.109
70	4.000	149.978	37.489	7.919	230.354	29.123	29.123	15.572	364.290	23.395	30.426	23.395	30.426	4.000	588.529	19.343	0.009
75	4.416	170.792	38.677	9.179	272.631	29.702	29.702	18.945	444.631	23.680	38.833	23.680	38.833	4.416	756.654	19.485	0.000
80	4.875	199.772	39.745	10.641	321.857	30.201	30.201	23.050	551.245	23.915	49.561	23.915	49.561	4.875	971.229	19.596	0.000
85	5.383	229.144	40.711	12.336	377.863	30.631	30.631	28.044	676.090	24.109	63.254	24.109	63.254	5.383	1245.087	19.684	0.000
90	5.943	247.157	41.587	14.300	443.349	31.002	31.002	34.119	827.983	24.267	80.730	24.267	80.730	5.943	1594.607	19.752	0.000
95	6.562	278.085	42.380	16.578	519.272	31.923	31.923	41.511	1012.785	24.398	103.035	24.398	103.035	6.562	2040.694	19.806	0.000
100	7.245	312.232	43.098	19.219	607.288	31.999	31.999	50.505	1237.624	24.505	131.501	24.505	131.501	7.245	2610.025	19.848	0.000

Table 412-1. Continued.

	6%				7%				8%				10%			
	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor	Single Payment	Compound Amount Factor	Uniform Annual Series	Present Worth Factor
n	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$\frac{1}{(1+i)^n}$	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$\frac{1}{(1+i)^n}$	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$\frac{1}{(1+i)^n}$	$(1+i)^n$	$\frac{(1+i)^n - 1}{i}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	n
1	1.060	1.000	0.943	1.070	1.000	2.070	0.935	1.080	1.000	2.080	0.926	1.100	1.000	2.100	0.909	1
2	1.124	2.060	1.833	1.145	2.070	3.215	1.808	1.166	2.080	3.246	1.783	1.210	2.100	3.310	1.736	2
3	1.191	3.184	2.673	1.225	3.215	4.440	2.624	1.260	3.246	4.506	2.577	1.331	3.310	4.641	2.487	3
4	1.262	4.375	3.465	1.311	4.440	5.751	3.387	1.360	4.506	5.867	3.312	1.464	4.641	5.867	3.170	4
5	1.338	5.637	4.212	1.403	5.751	7.153	4.100	1.469	5.867	7.336	3.993	1.611	6.105	7.153	3.791	5
6	1.419	6.975	4.917	1.501	7.153	8.654	4.767	1.587	7.336	8.923	4.623	1.772	7.716	8.487	4.355	6
7	1.504	8.394	5.582	1.606	8.654	10.260	5.389	1.714	8.923	10.637	5.206	1.949	9.487	9.937	4.868	7
8	1.594	9.897	6.210	1.718	10.260	11.978	5.971	1.851	10.637	12.488	5.747	2.144	11.436	11.579	5.335	8
9	1.689	11.491	6.802	1.838	11.978	13.816	6.515	1.999	12.488	14.487	6.247	2.358	13.579	13.937	5.759	9
10	1.791	13.181	7.360	1.967	13.816	15.784	7.024	2.159	14.487	16.645	6.710	2.594	15.937	15.937	6.144	10
11	1.898	14.972	7.887	2.105	15.784	17.888	7.499	2.332	16.645	18.977	7.139	2.853	18.531	18.531	6.495	11
12	2.012	16.870	8.384	2.252	17.888	20.141	7.943	2.518	18.977	21.345	7.536	3.138	21.384	21.384	6.814	12
13	2.133	18.882	8.853	2.410	20.141	22.550	8.358	2.720	21.345	24.215	7.904	3.452	24.523	24.523	7.103	13
14	2.261	21.015	9.295	2.579	22.550	25.129	8.745	2.937	24.215	27.152	8.244	3.797	27.975	27.975	7.367	14
15	2.397	23.276	9.712	2.759	25.129	27.888	9.108	3.172	27.152	30.324	8.559	4.177	31.772	31.772	7.606	15
16	2.540	25.673	10.106	2.952	27.888	30.840	9.447	3.426	30.324	33.750	8.851	4.595	35.950	35.950	7.824	16
17	2.693	28.213	10.477	3.159	30.840	33.999	9.763	3.700	33.750	37.450	9.122	5.054	40.545	40.545	8.022	17
18	2.854	30.906	10.828	3.380	33.999	37.379	10.059	3.966	37.450	41.446	9.372	5.560	45.599	45.599	8.201	18
19	3.026	33.760	11.158	3.617	37.379	40.995	10.336	4.316	41.446	45.762	9.604	6.116	51.159	51.159	8.365	19
20	3.207	36.786	11.470	3.870	40.995	44.865	10.594	4.661	45.762	50.423	9.818	6.727	57.275	57.275	8.514	20
21	3.400	39.993	11.764	4.141	44.865	49.006	10.836	5.034	50.423	55.457	10.017	7.400	64.002	64.002	8.649	21
22	3.604	43.392	12.042	4.430	49.006	53.436	11.061	5.437	55.457	60.755	10.201	8.140	71.403	71.403	8.772	22
23	3.820	46.996	12.303	4.741	53.436	58.177	11.272	5.871	60.755	67.755	10.371	8.954	79.547	79.547	8.883	23
24	4.049	50.816	12.550	5.072	58.177	63.249	11.469	6.341	67.755	73.106	10.529	9.850	88.497	88.497	8.985	24
25	4.292	54.865	12.783	5.427	63.249	68.676	11.654	6.848	73.106	79.954	10.675	10.835	98.347	98.347	9.077	25
26	4.549	59.156	13.003	5.807	68.676	74.484	11.826	7.396	79.954	87.351	10.810	11.918	109.182	109.182	9.161	26
27	4.822	63.706	13.211	6.214	74.484	80.698	11.987	7.988	87.351	95.339	11.093	13.110	121.100	121.100	9.237	27
28	5.112	68.528	13.406	6.649	80.698	87.347	12.137	8.627	95.339	103.966	11.258	14.421	134.210	134.210	9.307	28
29	5.413	73.640	13.591	7.114	87.347	94.461	12.278	9.317	103.966	113.283	11.415	15.863	148.631	148.631	9.370	29
30	5.743	79.058	13.765	7.612	94.461	102.073	12.409	10.063	113.283	123.346	11.550	17.449	164.494	164.494	9.427	30
31	6.088	84.802	13.929	8.145	102.073	110.218	12.532	10.868	123.346	134.214	11.635	19.194	181.943	181.943	9.479	31
32	6.453	90.890	14.084	8.715	110.218	118.933	12.647	11.737	134.214	145.951	11.737	21.114	201.138	201.138	9.526	32
33	6.841	97.343	14.230	9.325	118.933	128.259	12.754	12.606	145.951	158.627	11.857	23.225	222.257	222.257	9.569	33
34	7.251	104.184	14.368	9.978	128.259	138.237	12.854	13.690	158.627	172.317	11.992	25.548	245.477	245.477	9.609	34
35	7.686	111.435	14.498	10.677	138.237	149.635	12.948	14.785	172.317	188.923	12.141	28.102	271.024	271.024	9.644	35
40	10.286	154.762	15.046	14.974	199.635	228.749	13.332	21.725	228.749	259.057	12.474	45.259	442.593	442.593	9.779	40
45	13.765	212.744	15.456	21.002	288.749	338.854	13.666	31.920	338.854	386.506	12.488	72.890	718.905	718.905	9.863	45
50	18.420	290.336	15.762	29.457	406.529	475.657	13.801	46.902	475.657	533.913	12.494	117.391	1160.909	1160.909	9.915	50
55	24.650	394.172	15.991	41.315	575.929	657.520	13.940	68.914	657.520	733.213	12.519	189.059	1880.591	1880.591	9.947	55
60	32.988	533.128	16.161	57.946	813.520	916.214	14.039	101.257	916.214	1000.000	12.541	303.482	3034.816	3034.816	9.967	60
65	44.145	719.083	16.289	81.273	1146.755	1261.234	14.110	148.780	1261.234	1370.000	12.561	490.371	4893.707	4893.707	9.980	65
70	59.076	967.932	16.385	113.989	1614.134	1726.657	14.160	218.606	1726.657	2000.000	12.577	789.747	7887.470	7887.470	9.987	70
75	79.057	1300.949	16.456	159.576	2269.657	2400.000	14.216	321.205	2400.000	2748.456	12.586	1271.895	12708.954	12708.954	9.992	75
80	105.796	1746.600	16.509	224.234	3189.063	3189.063	14.222	471.955	3189.063	3865.935	12.594	2048.400	20474.002	20474.002	9.995	80
85	141.579	2342.982	16.549	314.500	4478.576	4478.576	14.240	693.456	4478.576	5533.913	12.599	3298.969	32979.690	32979.690	9.997	85
90	189.465	3141.075	16.579	441.103	6287.185	6287.185	14.253	1018.915	6287.185	7770.000	12.602	5313.023	53120.226	53120.226	9.998	90
95	253.546	4209.104	16.601	618.670	8823.854	8823.854	14.263	1497.121	8823.854	10970.000	12.604	8556.676	85536.760	85536.760	9.999	95
100	339.302	5638.368	16.618	867.716	12381.662	12381.662	14.269	2199.761	12381.662	14784.516	12.606	13780.612	137796.123	137796.123	9.999	100

Table 412-1. Continued.

15%				20%			
n	Single Payment	Uniform Annual Series		Single Payment	Uniform Annual Series		n
	Compound Amount Factor	Compound Amount Factor	Present Worth Factor	Compound Amount Factor	Compound Amount Factor	Present Worth Factor	
	$(1+i)^n$	$\frac{(1+i)^n-1}{i}$	$\frac{(1+i)^n-1}{i(1+i)^n}$	$(1+i)^n$	$\frac{(1+i)^n-1}{i}$	$\frac{(1+i)^n-1}{i(1+i)^n}$	
1	1.150	1.000	0.870	1.200	1.000	0.833	1
2	1.322	2.150	1.626	1.440	2.200	1.528	2
3	1.521	3.472	2.283	1.728	3.640	2.106	3
4	1.749	4.993	2.855	2.074	5.368	2.589	4
5	2.011	6.742	3.352	2.488	7.442	2.991	5
6	2.313	8.754	3.784	2.986	9.930	3.326	6
7	2.660	11.067	4.160	3.583	12.916	3.605	7
8	3.059	13.727	4.487	4.300	16.499	3.837	8
9	3.518	16.786	4.772	5.160	20.799	4.031	9
10	4.046	20.304	5.019	6.192	25.959	4.192	10
11	4.652	24.349	5.234	7.430	32.150	4.327	11
12	5.350	29.002	5.421	8.916	39.581	4.439	12
13	6.153	34.352	5.583	10.699	48.497	4.533	13
14	7.076	40.505	5.724	12.839	59.196	4.611	14
15	8.137	47.580	5.847	15.407	72.035	4.675	15
16	9.358	55.717	5.954	18.488	87.442	4.730	16
17	10.761	65.075	6.047	22.186	105.931	4.775	17
18	12.375	75.836	6.128	26.623	128.117	4.812	18
19	14.232	88.212	6.198	31.948	154.740	4.843	19
20	16.367	102.444	6.259	38.338	186.688	4.870	20
21	18.821	118.810	6.312	46.005	225.025	4.891	21
22	21.645	137.631	6.359	55.206	271.031	4.909	22
23	24.891	159.276	6.399	66.247	326.237	4.925	23
24	28.625	184.168	6.434	79.497	392.484	4.937	24
25	32.919	212.793	6.464	95.396	471.981	4.948	25
26	37.857	245.711	6.491	114.475	567.377	4.956	26
27	43.535	283.569	6.514	137.371	681.853	4.964	27
28	50.066	327.104	6.534	164.845	819.223	4.970	28
29	57.575	377.170	6.551	197.813	984.068	4.975	29
30	66.212	434.745	6.566	237.376	1181.881	4.979	30
31	76.143	500.956	6.579	284.851	1419.257	4.982	31
32	87.565	577.099	6.591	341.822	1704.108	4.985	32
33	100.700	664.664	6.600	410.186	2045.930	4.988	33
34	115.805	765.364	6.609	492.223	2456.116	4.990	34
35	133.176	881.170	6.617	590.668	2948.339	4.992	35
40	267.863	1779.090	6.642	1469.772	7343.858	4.997	40
45	538.769	3585.128	6.654	3657.258	18281.331	4.999	45
50	1083.657	7217.716	6.661	9100.427	45497.191	4.999	50

420 LIVESTOCK

CHAPTER 421 SWINE

This chapter summarizes what agricultural engineering can offer swine producers. It deals with the design and operation of the buildings and equipment necessary for a profitable swine business. Animal science, economics, and related subjects are mentioned only as they affect an engineering problem.

- As you consider alternatives, allow for:
Expansion, perhaps to twice the production you are now planning.

Your Neighbors, who may object to noise, odor, and dust from your business.

Regulations, which may dictate or limit building locations and waste disposal methods.

- Some decisions to be made early are:

Product To Be Marketed

Feeder pigs
Market weight hogs
Breeding stock

Pasture vs Confinement

Building System

PRODUCTION ALTERNATIVES

PRODUCT TO BE MARKETING

Farrowing Pigs For Sale As Feeder Pigs

A well designed farrowing system needs good farrowing facilities and expert management. A multiple-litter farrowing schedule will supply the most pigs with a given investment in buildings and equipment. Confinement housing is recommended to provide necessary environmental controls. Feeder pig production is recommended when:

- available space is limited, but expansion is desired.
- feed supplies for finishing pigs are unavailable or costly.
- labor is available, but capital is limited.
- a regular income with low investment is desired.
- there is local demand for feeder pigs.

Farrowing Pigs For Sale As Market Hogs

Good farrowing facilities are needed here too. In addition, and especially when a large number of pigs will be produced, separate facilities for each age group are recommended, for better disease and environmental control and waste handling. The number and size of facilities depends on:

- number of sows to be farrowed and the farrowing schedule.
- management system used—pasture, confinement, or combination.
- number of pigs desired.
- number of pigs purchased as feeder pigs.
- climate of the area.

Buying and Finishing Feeder Pigs

This system of production does not require farrowing facilities, and is recommended when:

- caring for baby pigs is not desired.
- labor is limited, and finishing feeds are available.
- there is a reliable source of feeder pigs.

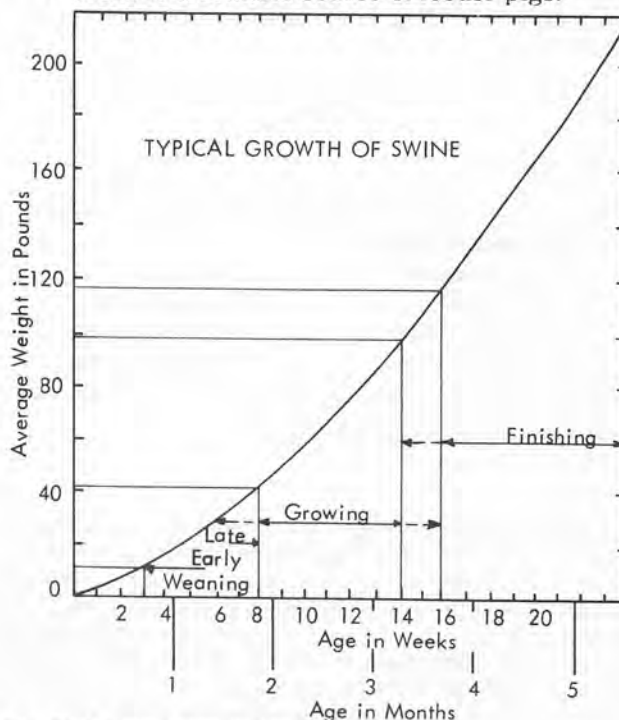


Fig 421-1. Typical growth of swine.

PASTURE VS CONFINEMENT

Pasture management is most practical for operators who:

- want to feed out pigs with minimum building investment.
- have pasture available for proper rotation for disease control.
- are tenants.
- farrow once or twice a year.
- farrow up to about 80 sows per year.

Partial or total confinement systems are recommended when:

- top level management is available.
- a multiple-litter farrowing schedule is used.
- large numbers of hogs will be raised.
- labor and available space is limited.
- capital is available.

Producers raise hogs in confinement:

- to cut labor and chore time with mechanical feeding and watering.
- to increase efficiency with better control of feed, diseases and other management practices.
- to provide better year-round working conditions for themselves.
- to reduce animal use of high value land.

Protect pigs on pasture from high temperatures with sun shades, waterers, sprinklers, and wallows. The hogs need shelter during cold weather where they can group together for warmth.

Producers using confinement housing can more easily moderate and stabilize temperatures, and control certain infectious diseases and parasites.

Control temperatures with ventilating fans, heaters, insulation, and in hot weather, sprinklers. Infectious diseases and parasites can often be controlled by isolation from other pigs and livestock, fumigation and other sanitation procedures, effective waste handling and health care, and close supervision.

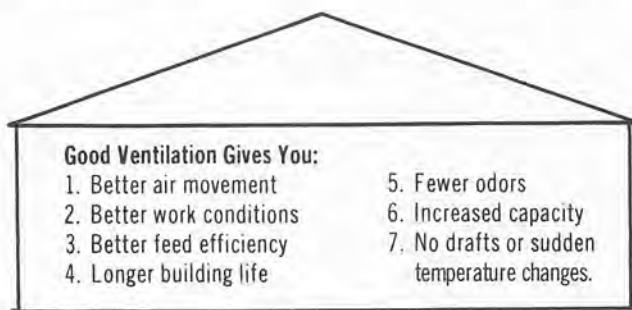


Fig 421-2. Advantages of good ventilation.

There is little manure handling in pasture systems, as the pigs are moved from pasture to pasture. Confinement systems must be designed to permit handling and disposing of all manure. The quantity of manure to be handled often influences the decision on how it will be done. Any waste disposal system must meet state and national requirements for water and air pollution control.

BUILDING LOCATION

Consider the following factors:

- **Drainage.** Drainage should be away from the farm home and other buildings. Pasture or feedlot drainage should not enter waterways leading to streams or lakes.
- **Future plans for expansion.** Always leave room for more buildings to be located properly with respect to feed storages and roads.
- **Snow, sun, and wind.** Some production systems require snow control for best efficiency. Locate facilities downwind from residences to minimize odor problems.
- **Feeding and marketing access.** Plan for the necessary movement of the operator, animals, and equipment.
- **Accessibility of water and electric lines.**

BUILDING SYSTEMS

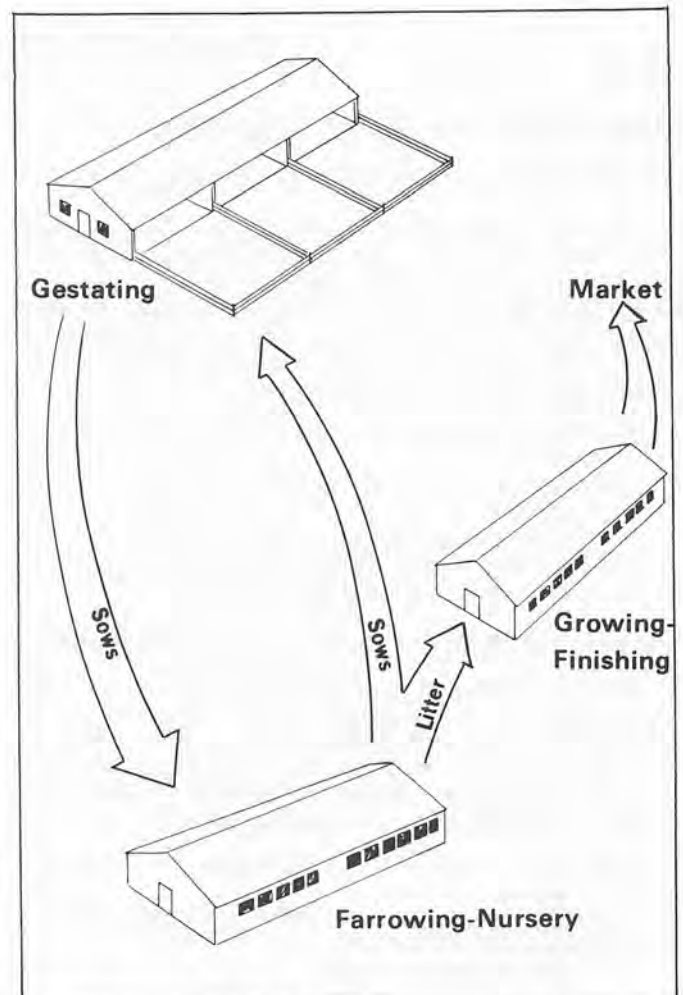
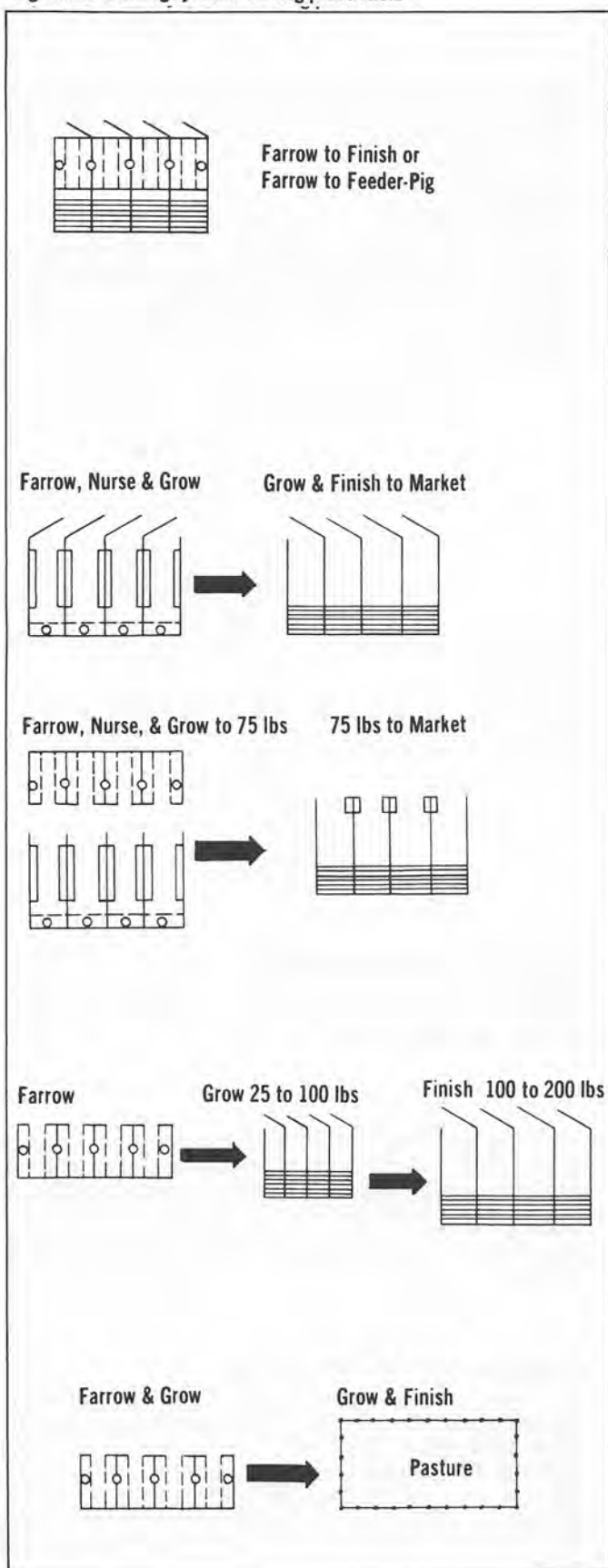


Fig 421-3. A multiple building system.

Fig 421-4. Building systems for hog production.



One-Stage Production

Farrow-to-finish production all in one pen has been tried, but is no longer common, partially because slower pigs in each group stay in the building too long, and there is not adequate clean-up time before the next farrowing. Space is not used efficiently. Further, the greater expense justified in a farrowing facility is not needed for a finishing facility.

Feeder pig production is commonly a one-stage system, with pigs sold from the pens in which they were farrowed. About 4 litters a year can be raised to 40 to 60 lb in a single pen.

Two-Stage Production

If pigs are farrowed, nursed, weaned and started in one pen to about 60 lbs and 12 weeks of age, they can be moved to a finishing unit for the next 12 weeks. About 4 litters a year can be raised this way. Some producers farrow 3 times per year—skipping a mid-winter litter and spreading the other 3 out a little, leaving more time for slower pigs to reach 220 lbs. Or, there may be farrowing stalls or pens for about half the sow herd, with nursery pens for the other half. Half of the sows are put into the stalls for farrowing. Sows with the largest pigs are moved to a nursery pen when the stalls are needed for another farrowing. The second "shift" of sows and litters stays in the stalls until weaning. About 2 litters are grouped into each nursery pen, often after sorting by weight and vigor.

Three-Stage Production

Three stages are common, especially for large herds and 6 or more farrowings per year: farrowing in stalls where pigs are held until weaning; starting or growing in pens with supplemental heat, for pigs to weights between 75 and 125 lb; and finishing in a unit for pigs up to market weight. As in two-stage systems, some sows and litters may be moved to nursery pens before weaning.

Others

The 1-, 2-, and 3-stage systems above refer to the number and types of buildings needed. Depending on climate and program, pasture may substitute for one or more buildings for all or part of a year. And, the stages may be on different farms, as with a typical feeder-pig program.

FARROWING

Typical Farrowing Schedules

- **One Litter Per Year.** Gilts are farrowed once a year in warm weather, often on pasture. The investment in buildings and equipment can be very small, but the cost is charged to only one group of sows and litters.
- **Two Litters Per Year.** One group of sows is farrowed twice a year. If one of the farrowings is in cold weather, more investment in buildings and equipment is justified; overhead is prorated to twice as many litters.
- **Multiple Litters Per Year.** Two or more groups of sows are each farrowed twice a year. Confinement facilities are helpful for this schedule; facilities are charged to many pigs, so the cost per pig may be the lowest of all possible schedules.

Farrowing Buildings

Farrowing in an enclosed building allows the manager to control the environment within the building. Baby pigs must be kept warm, dry, and free from cold drafts. A new-born pig needs an environment of about 90°F, then is content with about a 2° drop per day to 70°F. The sow, on the other hand, is most comfortable at about 60°F. To obtain these two temperatures at the same time, provide supplemental heat in the creep area. Creep heaters may be lamps, gas heaters, electric heating cable or hot water pipe in the floor, or some combination.



Fig 421-5. Supplemental heat in creep area.

Provide supplemental heat for at least the first week after birth, and longer if the building temperature would fall below 60°F. Some producers with farrowing stalls on slotted floors use no supplemental heat, but heat the entire building to 80°F.

However, if pigs like 90°F, they still benefit from a heat lamp. For additional information see the chapter on Ventilation.

Stalls and Pens

Stalls (or Crates)

Farrowing stalls provide the best protection from injury for small pigs (particularly for the first week or two) and also require less bedding, floor space, and labor than do pens. It is more difficult to catch pigs in a stall.

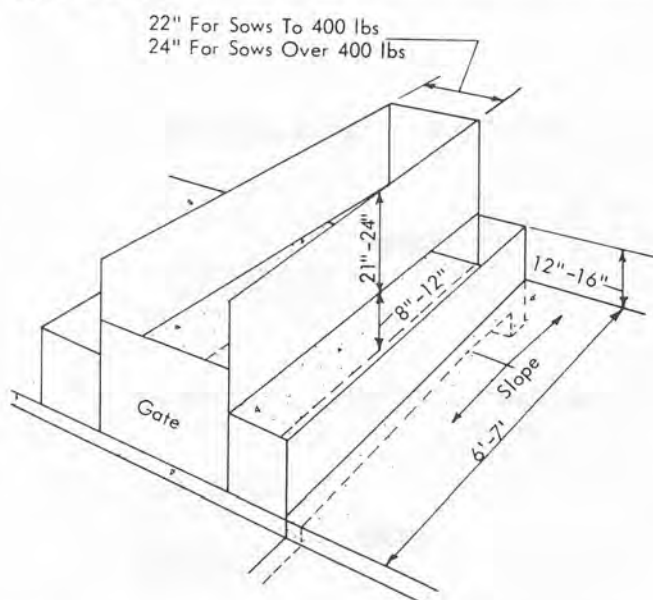


Fig 421-6. Farrowing stall dimensions.

Farrowing stalls are commonly built from 1" lumber, 3/4" exterior plywood, or 1" galvanized pipe. Solid pig barriers can reduce drafts.

Many producers provide water and feed in each stall, while others release the sows daily. Feeding in stalls is especially recommended for larger herds.

The stall area is often used, by producers farrowing up to four times a year, to grow weaned pigs. The stall or crate may be removed at weaning.

Farrowing Stalls & Nursing Pens

Some managers do not wean all pigs in the farrowing stalls. Sows to farrow first are put in stalls, then they and their litters are moved to pens, leaving the stalls free for the rest of the sows. When the youngest pigs are perhaps 3 to 5 weeks old, sows are returned to the gestation area, and the pigs are sorted and grouped into the growing pens.

Pens

Farrowing pens provide greater freedom for the sow than do stalls, but require more cleaning. Pens may be preferred by producers practicing late weaning to give more space for the larger pigs.

Farrowing pens with feeders and waterers are easily converted to small growing pens by removing the guard rails. Finishing pens can be made by removing some of the partitions to make larger pens.

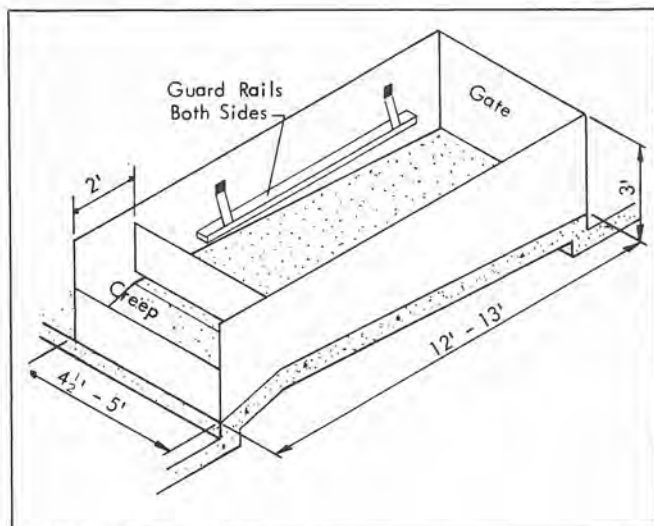


Fig 421-7. Farrowing pen dimensions.

Note the two-slope floor, which gives drainage from the creep area directly to the alley.

Free Stalls

Free stalls are farrowing pens modified so the sow can leave and enter at will. Baby pigs are restrained by the low gate behind the sow until they are accustomed to "home."

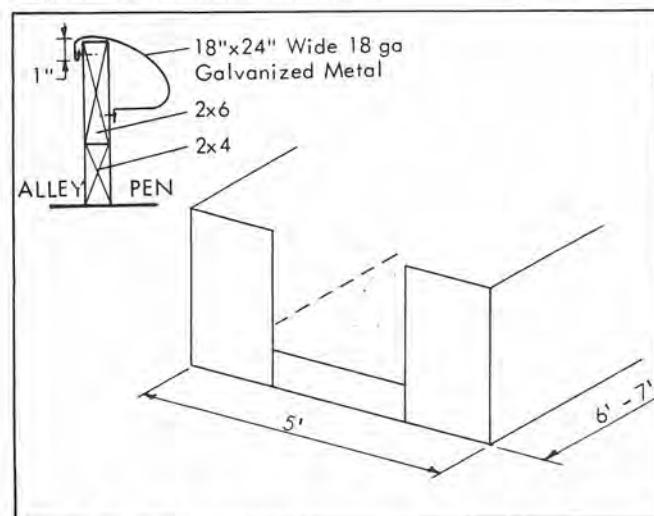


Fig 421-8. Free stall dimensions.

One type of homemade pig stop is shown; commercial units are available.

The advantages of free stalls relative to farrowing stalls are:

- Labor saving in turning sows out to eat.
- Labor saving in cleaning individual pens.
- Less investment in feeders and waterers.
- Cleaner pens.
- Most sows are more relaxed.

The disadvantages are:

- A sow may go out and in up to 15 times a day and usually lays down each time she enters the pen.
- If a sow does not want to nurse her litter she leaves the pen.
- Some sows carry bedding to the alley to make a farrowing nest.
- Sows leave pens quickly if there is any draft.
- If a few pigs get out, it is difficult to return them to the right pen unless they are marked.
- A sow can lie with her head through the door; pigs can crawl up on her and escape.
- If feeding space is limited, the sows may have to be fed in small groups.
- Some producers limit feeding the sows for up to 5 days to help control scours in baby pigs; so sows must be fed in the stalls.
- If the gate at the back of the pen is too high, an old sow with low slung udder is susceptible to mastitis.

Free-stall farrowing may be satisfactory:

- If the stall or pen is the most comfortable place for the sows.
- For the relatively small producer.
- With sows feeding in groups of 10 or fewer.
- If the farrowing area has flat floors, because sows dung outside the stalls.
- With indoor feeding, to eliminate frozen wastes and drafts from sow doors.

Floors

Slotted Floors

Slotted floors help keep floor cleaning to a minimum, especially if sows are fed in the stall or pen.



Fig 421-9. Farrowing on a partially slotted floor.

Manure under slotted floors must be handled as a liquid. Part of the floor may be left solid for electric or hot water floor heat. Floor or space heat, rather than bedding, is recommended with liquid manure handling.

Space slats either a uniform $3/8''$ apart, or $3/4''$ - $1''$ apart. Spaces between $3/8''$ and $3/4''$ are not recommended because pigs' legs may get caught. Space slats $1''$ apart behind the sow to improve cleaning. Cover any spacing over $3/8''$ during, and for 3 days after, farrowing. An opening about $2''$ by $4''$ behind the sow will aid cleaning.

Solid Floors

Slope solid floors to alleys and drains. A two-slope floor is recommended if waterers are installed in the stall or pen.

Table 421-1. Floor and alley slopes.

Alley Slopes

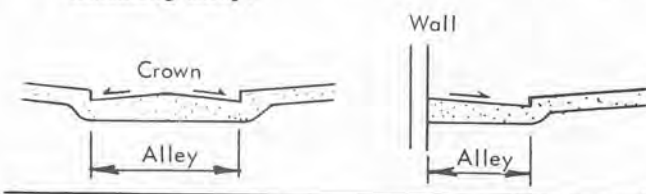
- $1/2''$ /ft cross slope to form a crown.
- $1/4''$ /ft to drains.

Floor Slopes

- Flat with slotted floors.
- $1/2''$ - $3/4''$ /ft, without bedding.
- $1/4''$ - $1/2''$ /ft, with bedding.

Alley Widths

- Feeding alley, 4' for feed cart.
- Sow handling alley, 3'.
- Remodeling, as little as 2' for feeding or sow handling alley.



Sow Wash

Install a sow wash near one entrance to the building for washing sows before farrowing.

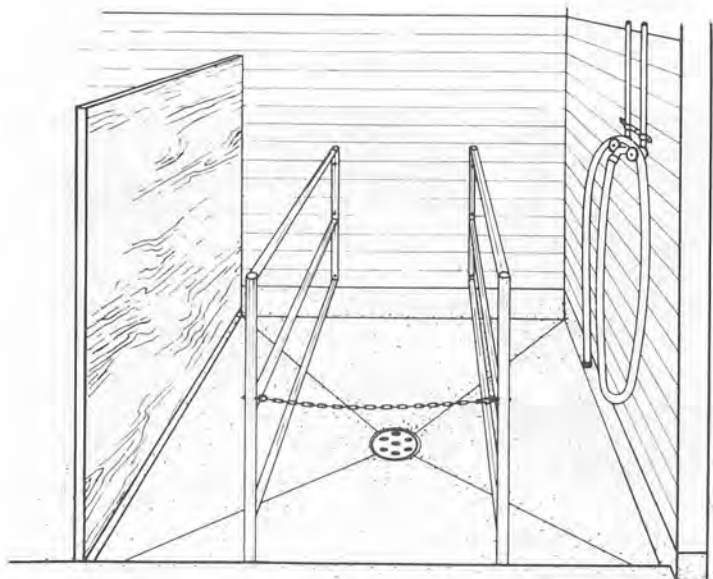


Fig 421-10. Sow wash pen.

Provide hot and cold water and slope the floor $1/4''$ - $1/2''$ /ft to a drain.

Selecting a Layout

Will Manure Be Handled as A Solid Or A Liquid?

The relatively small amount of wastes from a farrowing house do not justify getting special handling equipment. If other wastes on the farm are handled as liquids, and if capital can be invested to replace labor, consider slats and liquid handling of farrowing house wastes, especially for large herds.

Will The Sows Be Fed In Or Away From The Stalls Or Pens?

Odor from a feeding floor may be a problem, especially in hot weather. The trend among larger producers is to feed in the stalls to reduce the time of turning the sows in and out. Most farrowing units should be set up for hand feeding, because of the small amount of feed that is needed, and for observing each sow's appetite.

Will The Sows Face Each Other Or The Outer Walls?

Face-in arrangements require only one feed alley. Sows may be calmer if they can see entering visitors. Choose an arrangement with three alleys if possible.

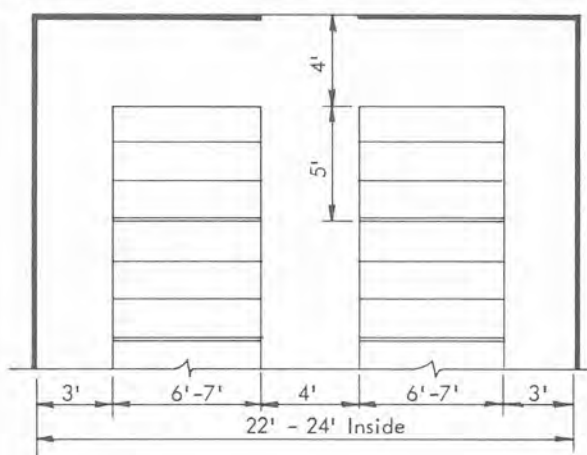
Will The Stall Or Pen Area Be Used For Growing?

If used only for farrowing, stalls rather than pens are suggested.

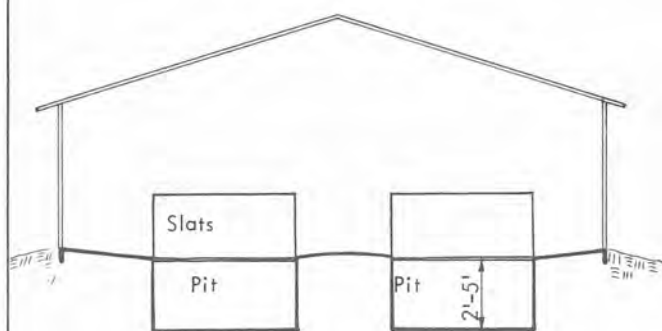
Separate feeding floors for sows eliminate carrying feed to the pens or stalls. Sows do most of their dunging in the feeding area. Sows are turned out each day to the feeding floor.

Provide about 2' of feeder space for each sow if all are fed at the same time. One foot of space is satisfactory if sows have free access to the feeder. Clean the feeding area about every third day in cold and mild weather. During hot weather, clean often to prevent sows from lying in the manure.

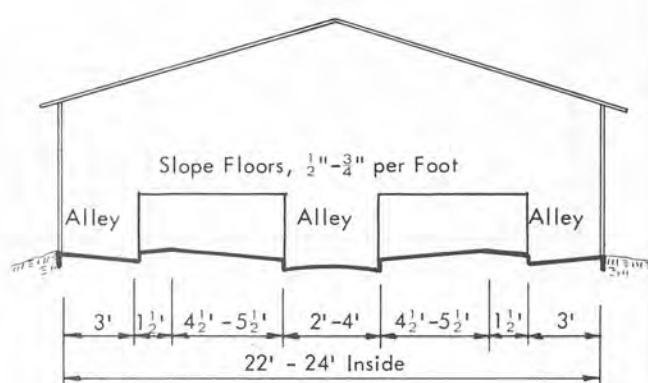
Fig 421-11. Buildings with farrowing stalls.



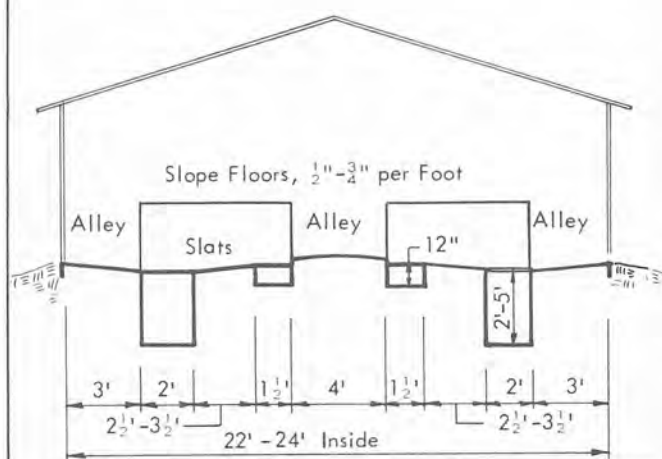
Note that solid floors slope to pits or gutters. Three alleys are suggested if sows are to be fed in the stalls, and for new farrowing houses. Sows commonly face in for easier feeding. Slats or partial slats are more easily justified with inside feeding.



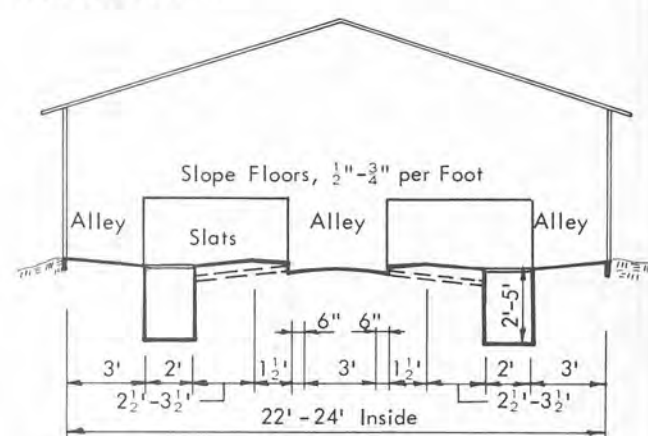
Full slats under farrowing stalls. The pit will store wastes for about 60 days per foot of depth.



Two-slope solid floor. Even if sows are fed in the stalls, the greater cleaning needed on solid floors suggests facing the sows out. Outside alleys may be omitted if sows are not fed in the stalls; consider possible future feeding programs.



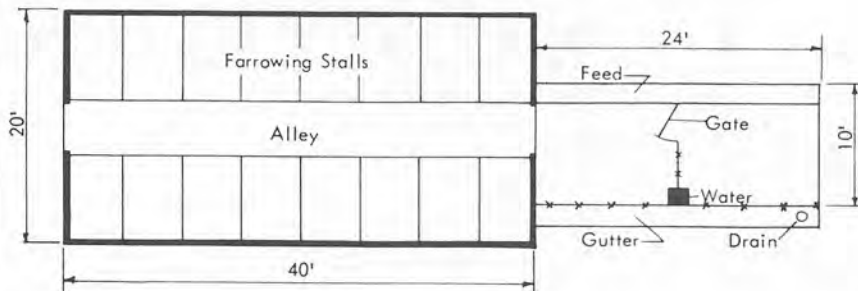
Partial slats under farrowing stalls. Slats or welded mesh in the front of the stalls helps keep small pigs clean, and drains spilled water. The pits will hold wastes for about 18 days per foot of depth.



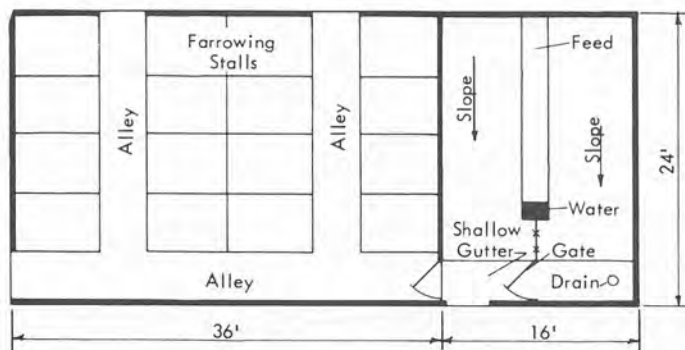
Partial slats and alley gutters. A small gutter in the alley does not need slats or a grill, but the alley must be wide enough for feedcart wheels to stay out of the gutter. Drain alley to pits about 20' o.c.

Fig 421-12. Buildings with farrowing stalls and feeding floors.

See two-stage production, page 229.

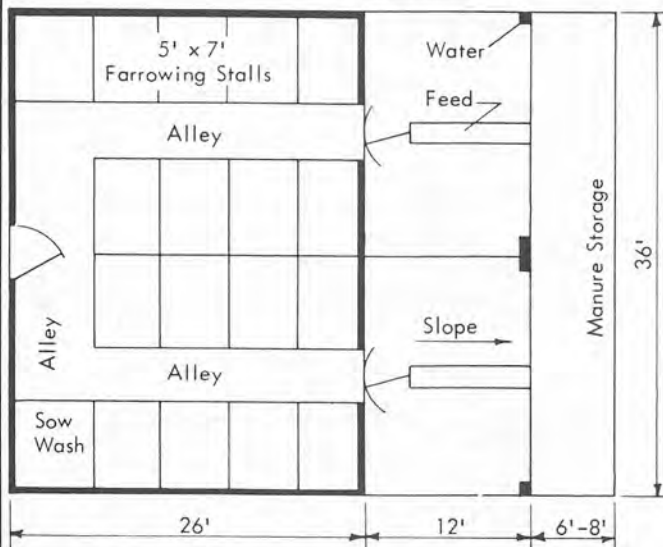


20' building, feed at one end. This is a minimum, but adequate, unit.

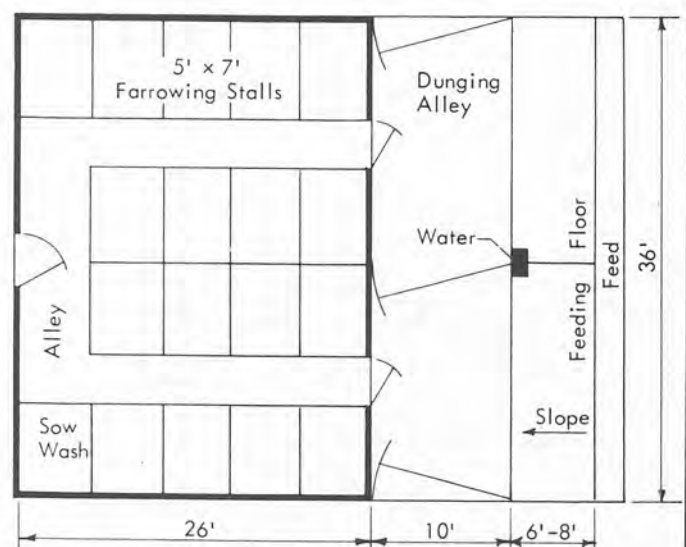


24' building, feed at one end. The 20 sows are handled in one group in this plan. An enclosed feeding area can include a sow-wash area.

A single alley behind the sow is enough if the sows are fed away from the stalls. A covered feeding floor is desirable.



26' building, hand cleaning. The plan provides for feeding sows in two groups. With older litters, pigs can be fed outdoors.



26' building, tractor cleaning. Gate arrangement and feeder location permit tractor scraping of the dunging alley. Sow herd may be divided.

Fig 421-13. Buildings with farrowing stalls and nursing pens.

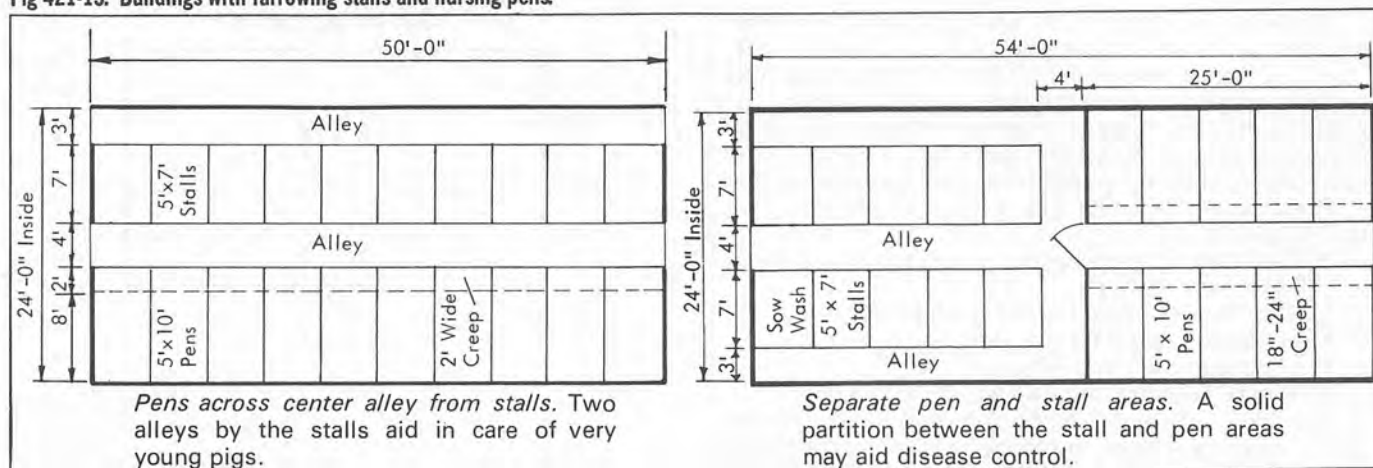
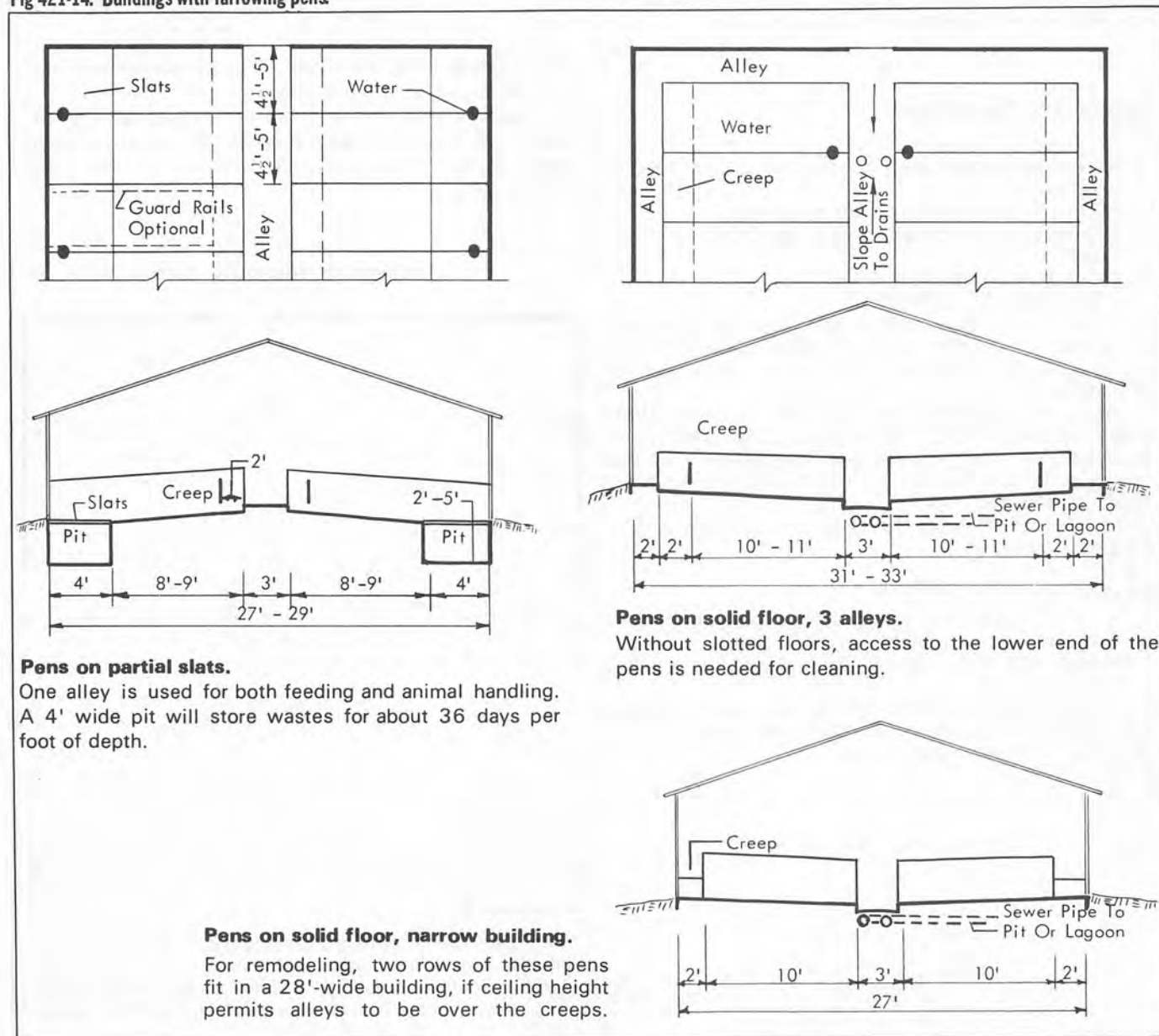


Fig 421-14. Buildings with farrowing pens.



GROWING

Growing is used to mean the period between weaning and when the pigs weigh about 100 lb.

An optimum environment for growing pigs may require large investments. But, when buildings and equipment are designed, installed, and operated properly, they will reduce labor and improve feed conversion, making possible higher overall profits.

Feed conversion is highest with an environment that includes:

- About 60°F temperature (weanlings up to about 60 lb need 70°F).
- Moderate relative humidity (50%-80%).
- Adequate space for each animal.
- Adequate feed and water.
- Effective sanitation and waste disposal.

Provide sufficient ventilation and heat. Install space heaters in the building, and/or install individual heaters for the resting area for small pigs in cold weather: heat lamps, radiant heaters, or underfloor electric cable or hot water pipe.

Space and Facilities

Growing pens may be:

- The farrowing stall or pen after the sow is removed.
- Pens in a separate growing building.
- Pens in a combination growing-finishing building.
- Subdivided finishing pens.
- Full sized finishing pens.

Provide each pig with from 3 to 4 sq ft of pen area until it reaches about 100 lb. Space recommendations for pigs over 100 lb are listed under "Finishing".

Size each growing pen to hold no more than about 25 pigs. More pigs per pen may result in a decrease in rate of gain and an increase in pig social problems. More variation in pig size may develop in larger pens.

Provide 1 drinking space/20 to 25 pigs, and 1 feeding space/4 pigs.

Selecting a Floor Plan

As you design or select a floor plan, consider:

- Where and how the pigs will be fed?
- How will the manure be handled—as a solid or a liquid?

At least partially slotted floors are recommended for growing pigs, because they are most apt to dirty all of a solid-floor pen.

Fig 421-15. Pen arrangements for growing pigs.

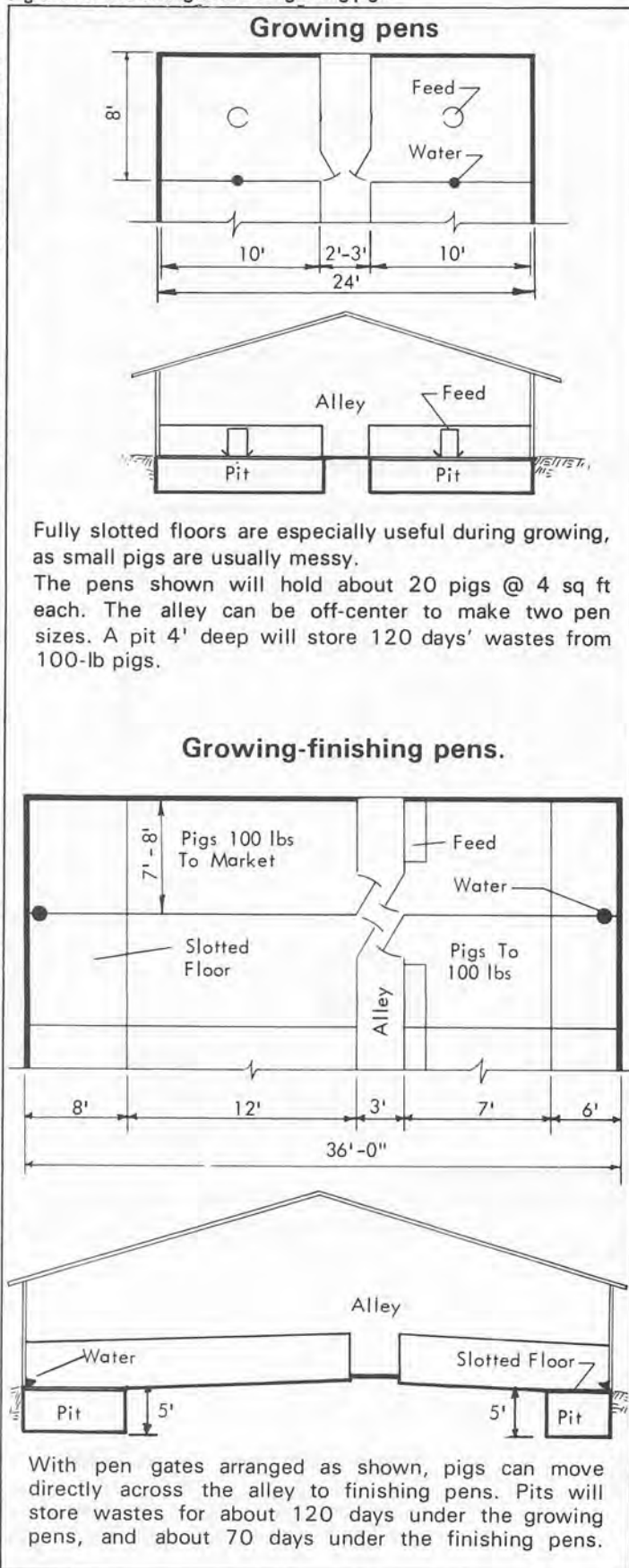
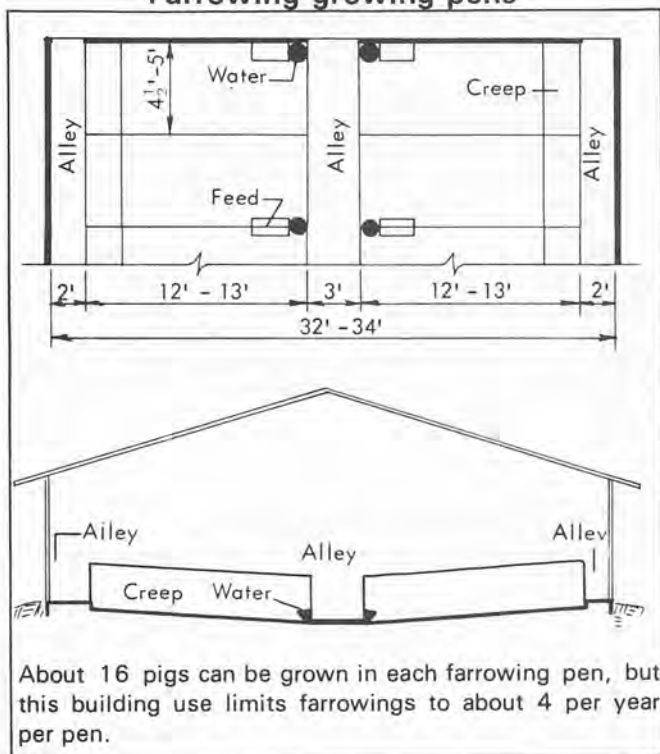
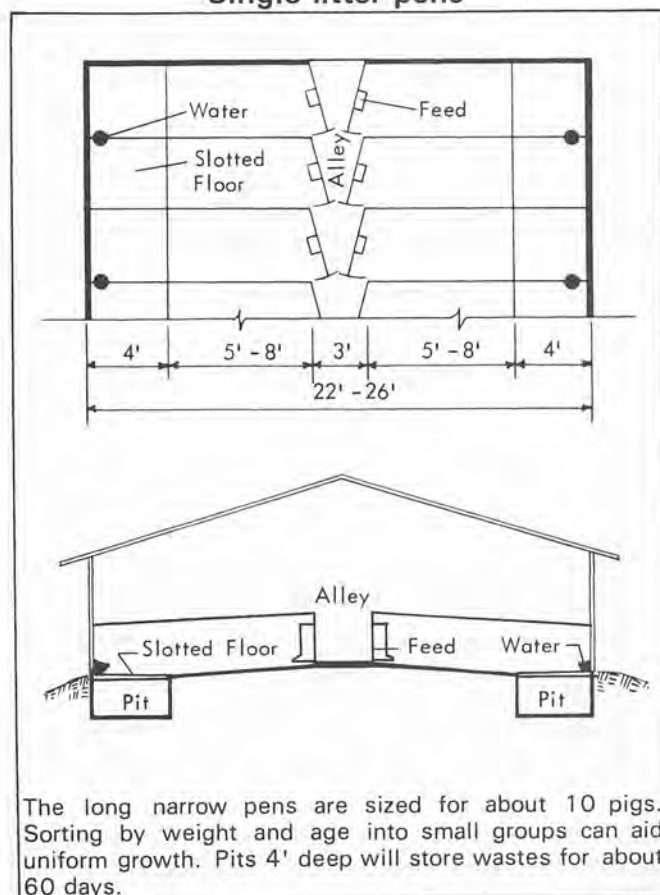


Fig 421-15. (continued)

Farrowing-growing pens**Single litter pens****FINISHING**

Finishing is the stage from pig weights of about 100 lb to market size. Finishing is practiced on pasture, shelter and drylot, in open front buildings, or in complete confinement. The following discussion assumes the pigs will be housed; there are successful drylots, but in most of the Midwest, covered feedlots are recommended.

Although a finishing pig can stand low temperatures, he grows fastest and with least feed at temperatures of about 55°F and at relative humidities of 50%-80%. See the chapter on "Ventilation".

Space requirements vary with pig size and type of pen floor (bedded, solid, or slotted). Overcrowding tends to increase tail-biting and cannibalism, and may decrease rates of gain. A larger number of animals per pen, especially if at minimum space per pig, has an effect similar to overcrowding. More space than recommended has not improved the rate of gain or pig social behavior.

Re-grouping animals causes stress, as they determine a new social order and adapt to their new surroundings. If litters must be grouped, it is best to group them early. Weak pigs can be penned together to reduce competition. Some producers also group injured pigs.

Space and Facilities

Provide about 6 sq ft of clear floor space for each 100 lb pig. Increase this space to about 8 sq ft when the pig reaches about 150 lbs. This can be done by:

- Transferring 1 or 2 pigs from each pen to empty pens.
- Removing or moving partitions.
- Moving the pigs to larger pens.

With a shelter and paved outdoor feeding floor, allow about 6 sq ft/pig indoors and 6 sq ft/pig outdoors.

Size finishing pens to hold not more than about 25 pigs.

Provide one drinking space for each 20 to 25 pigs. If self-feeders are used, provide 1 space for 4 pigs.

Slope floor areas to help with manure handling and cleanliness:

- 1/2" - 1"/ft, solid floors.
- 1"/ft, outside feeding floors.
- Usually flat, slotted floors.

Alleys:

- 1/2"/ft cross slope crown.
- 1/10"-1/4"/ft, to drains.
- 1"/25'-1"/100', gutter and pit floors, lengthwise.

Selecting a Layout

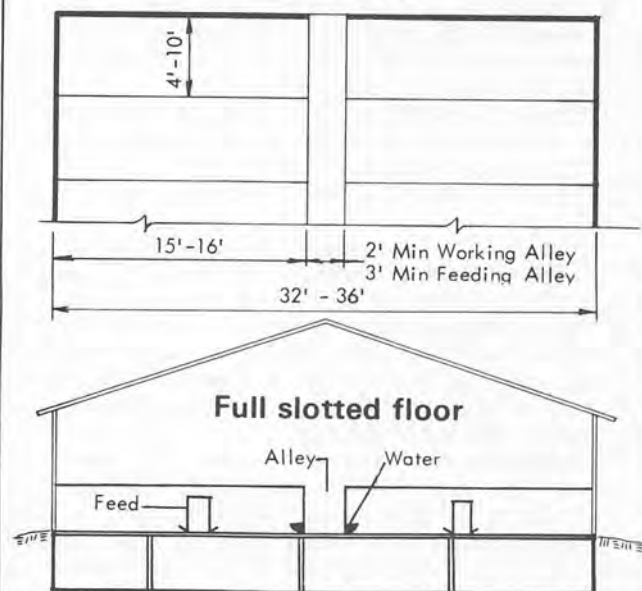
As you select a floor plan, consider:

- How will the manure be handled—solid or liquid?
- Where will the feeders and waterers be located?

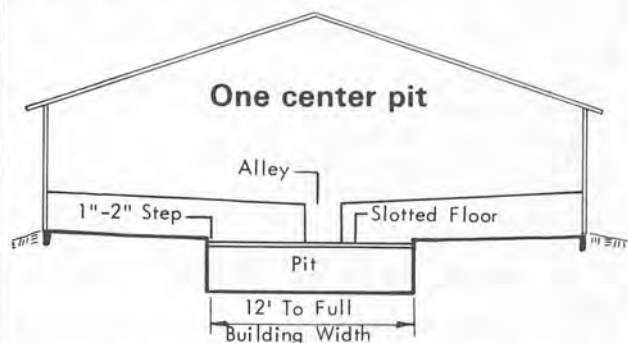
Locate feeders away from areas of manure deposit or collection, but locate waterers near these areas.

Fig 421-16. Finishing layouts—center alley, slotted floors.

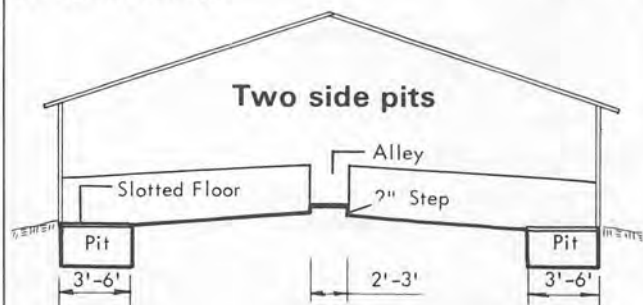
Building length depends on the number of pigs to be finished. At 8 sq ft/pig, each 4'x16' pen holds 8 pigs, and each 10'x16' pen holds 20 pigs.



Pen size and arrangement are very flexible. Hand cleaning is minimized, and manure storage capacity is relatively high—about 140 days in 4' deep pits.



A central pit is less apt to freeze and should be cheaper than two side pits but provides access only at the ends for agitating and pumping. The alley is slotted to save making two pits only 2'-3' apart. A central pit is easier to install than side pits in an existing building with good footings.



In cold climates, insulate to the frost line along outside pit walls. Pit will hold about 60 days' wastes.

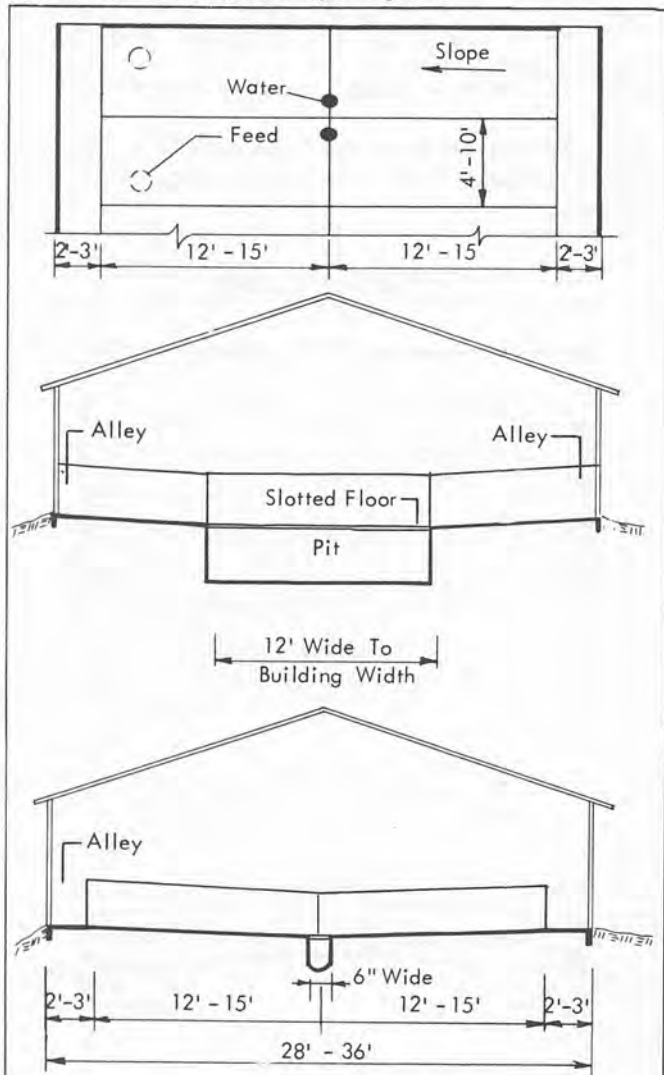
When slotted floors are included in your building:

- Locate the waterers over or near the slotted area.
- Install insulation to the frost line along pits near outside walls in colder climates.
- Waste disposal regulations may require more storage volume than pits under partially slotted floors. Wastes can be pumped to an outdoor tank.

When pigs are put into partially slotted floor pens, restrict them to the slotted area to encourage good dunging habits.

A 1"-2" step down from a solid floor to a slotted floor may help separate the dunging area and prevent some manure from working up on the solid floor.

Fig 421-17. Finishing layouts—alleys along walls.



Two side alleys require more building space than one central alley. Pens may be different widths, or the middle divider can be off-center.

Fig 421-18. Finishing layouts—narrow gutter.

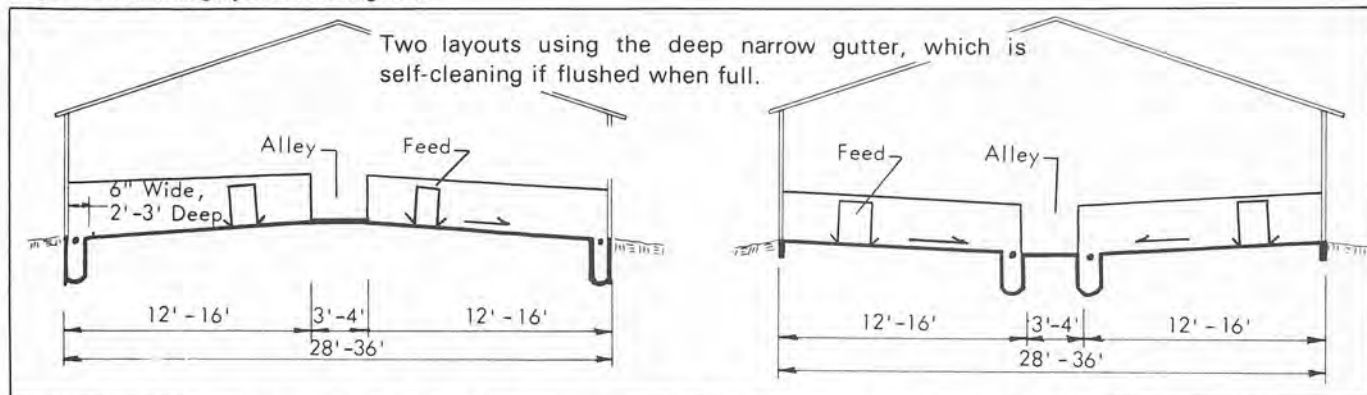
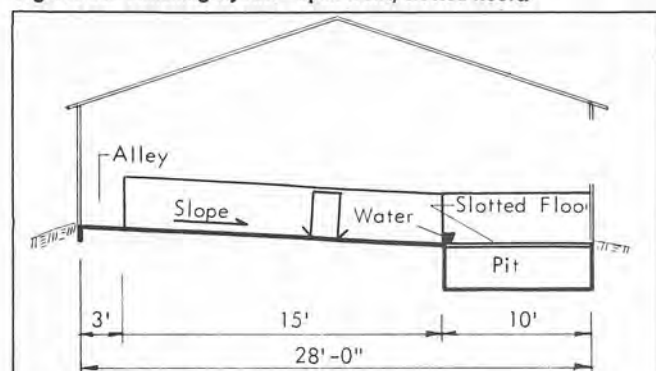
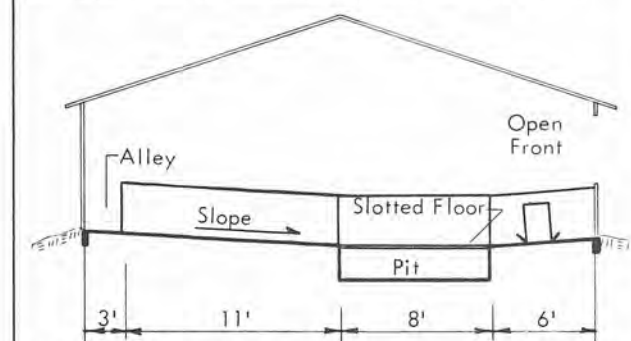


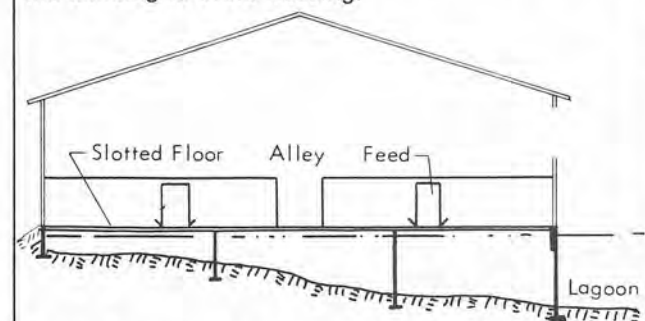
Fig 421-19. Finishing layouts—open front, slotted floors.



In warm or moderate climates, place the pits along the open wall for maximum winter sun exposure.

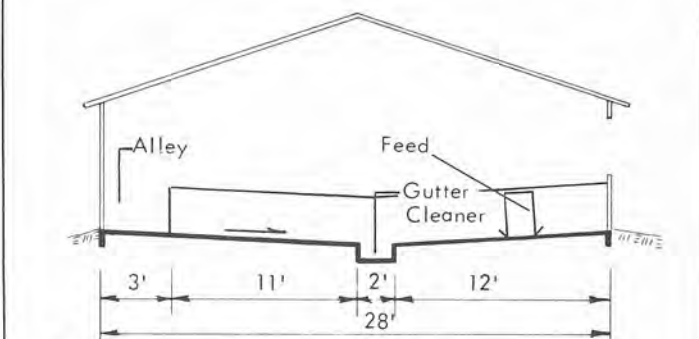
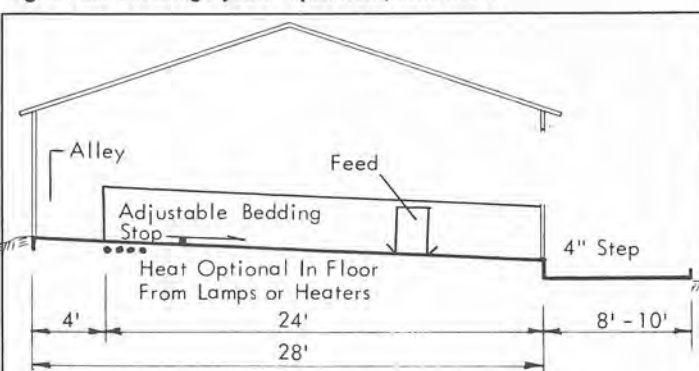


In cold climates, arrange the pit near the center of the building to avoid freezing.



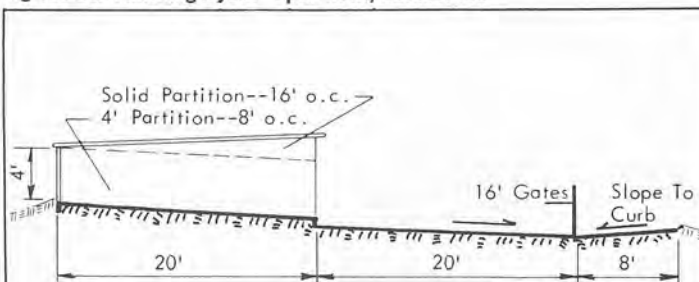
In warm climates where the lagoon will be active all year, a fully slotted floor finishing building can be over the edge of a lagoon. Floors will be drafty in cool weather.

Fig 421-20. Finishing layouts—open front, solid floors.



Bedding can be used on solid floors. Adding heat in the floor or with brooders is optional. These two layouts assume hand cleaning.

Fig 421-21. Finishing layout—open front, outdoor lot.



An open lot adds to cleaning and runoff control problems. Some units use floor heat both indoors and out for comfort and to avoid snow accumulation.

GESTATING SOW HOUSING

Care of gestating sows in total confinement is increasing in popularity because:

- Producers can maintain better control as sow herds increase in size, and in number of farrowings per year.
- Herds can be cleared of soil-borne parasites.
- Pasture may be used for crop production, saving fencing and other related costs.

However, high investment in buildings and equipment is needed.

Caring for gestating sows in confinement will not be practical or economical for many hog producers. Some of the conditions that favor pasture or non-confinement management include:

- Using marginal land not useful for crops.
- Cropping rotations that require pasture crops.
- Small numbers of farrowings.
- Limited capital.
- Production on rented land.

Sows may be limit fed either by offering 4 to 5 lb to each sow each day, or by full-feeding every third day.

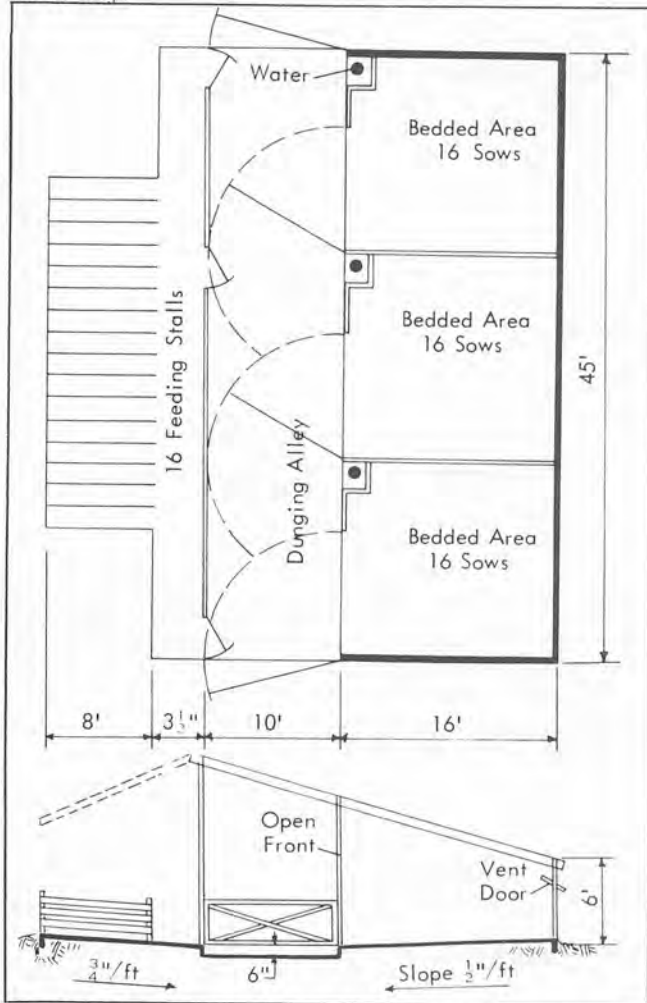


Fig 421-22. Open-front sow housing with feeding stalls.

Each pen of sows eats every third day. The dunging alley is arranged for tractor cleaning. A roof over the dunging and feeding areas is desirable.

Open Shelter Housing

The sows require bedding, so manure is handled as a solid. Each sow requires about 15 sq ft of bedded area.

Keep inside winter temperatures about the same as outside temperatures, or frost and condensation problems will develop.

In some units, only the bedded area is covered. But because it may become icy, a covered dunging alley is recommended in areas of heavy snow fall. Provide at least wind and snow protection for outdoor feeding floors. If the floor is covered, rain water will not be added to the wastes.

The two figures below show layouts suitable for feeding 3 groups of sows (one group at a time) in the same outside feeding area. Each day one group of 16 sows is turned into the stalls for controlled feeding.

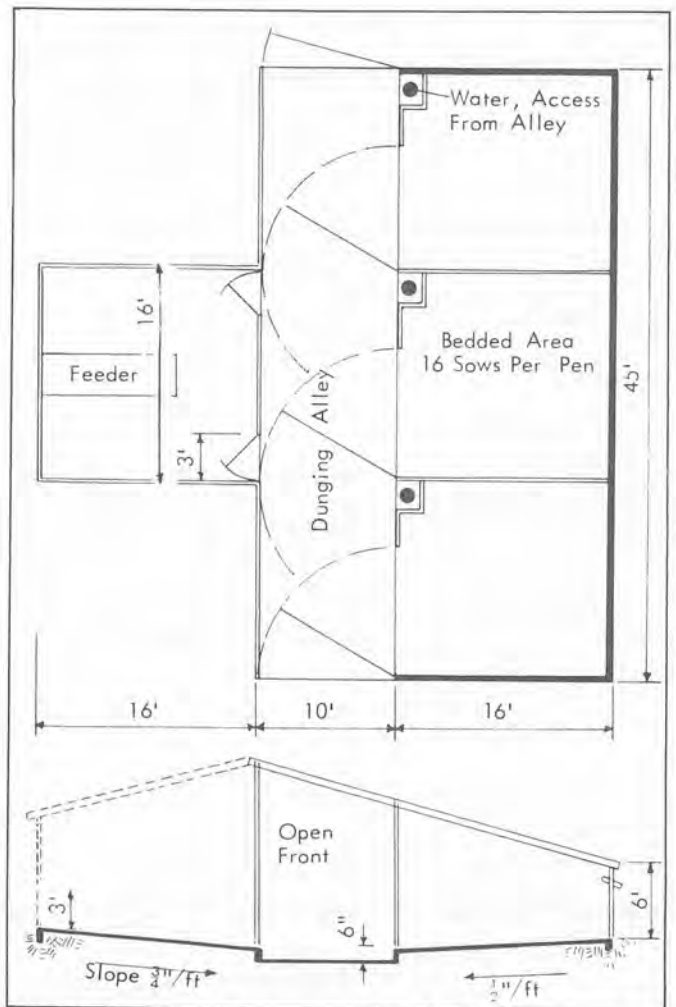


Fig 421-23. Open-front sow housing with self-feeder.

A layout arranged for a self-feeder instead of individual feeding stalls.

Confinement Sow Housing

Sows require no bedding in confinement housing; manure can be handled as a liquid if slotted floors are installed. Each sow requires 15 to 20 sq ft of building area.

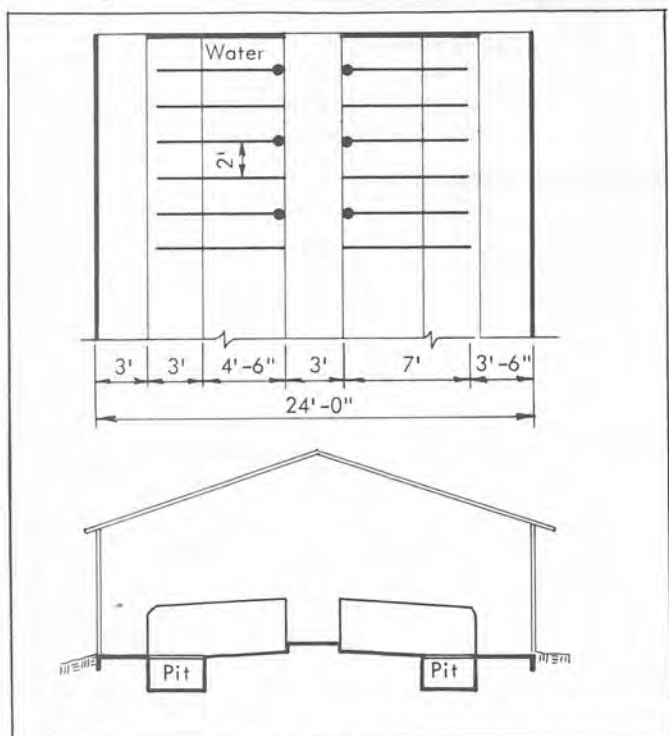


Fig 421-24. Sows in individual tie stalls.

Tying sows in stalls prevents fighting and competition for limited feed.

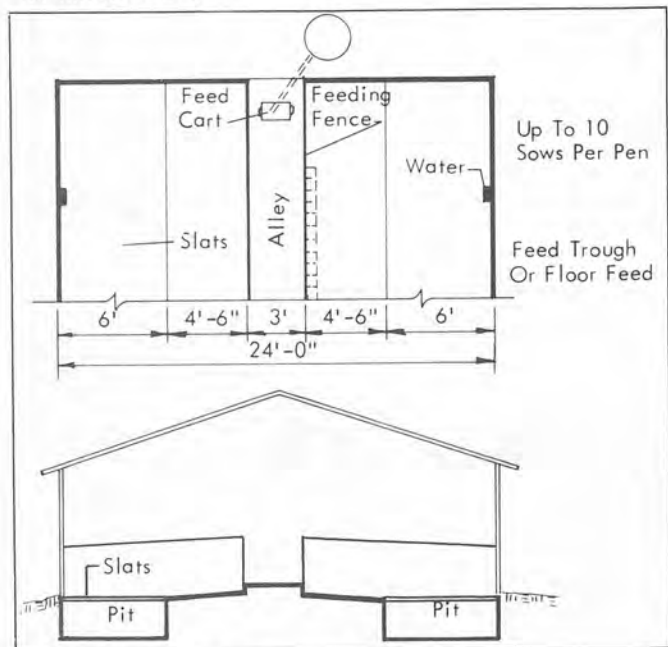


Fig 421-25. Sows fed in pen.

Sows in group pens can be fed on the floor or in feeders.

Sows can be fed in either pens or stalls, or moved to a separate part of the building equipped with feeding stalls or self-feeders. Feed may be hand or mechanically distributed. Floor feeding is common.

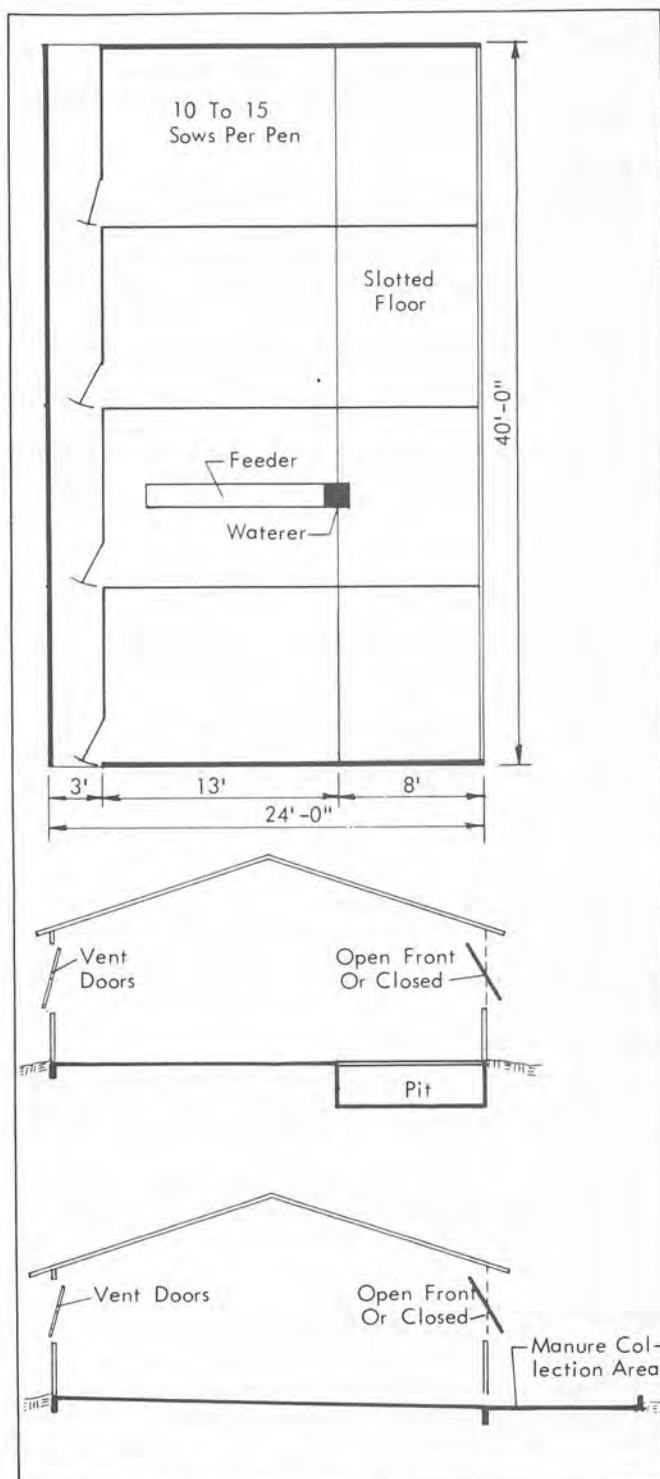


Fig 421-26. Sows in pens, separate feeding area.

These units are suitable for gestation sow housing with either solid or partially slotted floors. Doors along the open front are optional.

Breeding

A separate boar pen may be provided for individual breeding; a sow or gilt is moved into the boar's pen for mating. Conception may be reduced when breeding in confinement, especially with gilts.

Slotted Floors

Use a slot width of 1"-1 1/4" between 4"-8" wide slats. To eliminate almost all hand cleaning, the whole floor should be slotted.

Tie Stalls

Tying gestating sows in stalls with a strap or chain improves control of feeding (Fig 421-24). Gilts may be restless when first tied in a stall, but most will become content in a short time. Heat detection may be time consuming and difficult.

Construct stalls about 24" wide, 3'-7' long, and about 30" high. Center the tie-ring for the tether under each sow's neck, about 8" behind the feed trough.

Stall partitions should be open so sows can see each other to reduce restlessness when they are first tied.

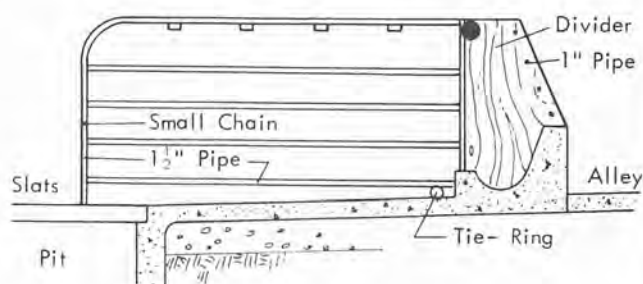


Fig 421-27. Tie stall for gestating sow.

A tie or tether stall does not need long or solid sides. A divided feed trough can reduce fighting, though sows can be floor fed.

Individual Feeding Stalls

These stalls allow limit feeding of each sow, and discourage bossism and fighting. Slower sows learn to sit down to avoid being bitten or driven from their stalls.

The stalls are very helpful in controlling dosages for drug feeding and may be used for artificial breeding and other types of sow care.

PASTURE PRODUCTION

Producing hogs on pasture usually requires less investment in buildings and equipment than does confinement production. Year-round production is difficult in cold climates.

Illustrated are the following recommendations:

- Provide shade and shelter. Move portable houses periodically.
- Locate feeders at a well-drained site, on pavement or wood platforms.

- Arrange pasture lots along a permanent road. Prevent wallows near waterers by forming a curb around the slab. Slope the slab toward the road.

Pasture Space Requirements

- 10 gestating sows/acre.
- 7 sows and litters/acre.
- 50 to 100 growing-finishing pigs/acre, depending on rainfall and fertility.

Shade Space Requirements

- 15-20 sq ft/sow.
- 20-30 sq ft/sow and litter.
- 4 sq ft/head to 100 lbs.
- 6 sq ft/head over 100 lbs.

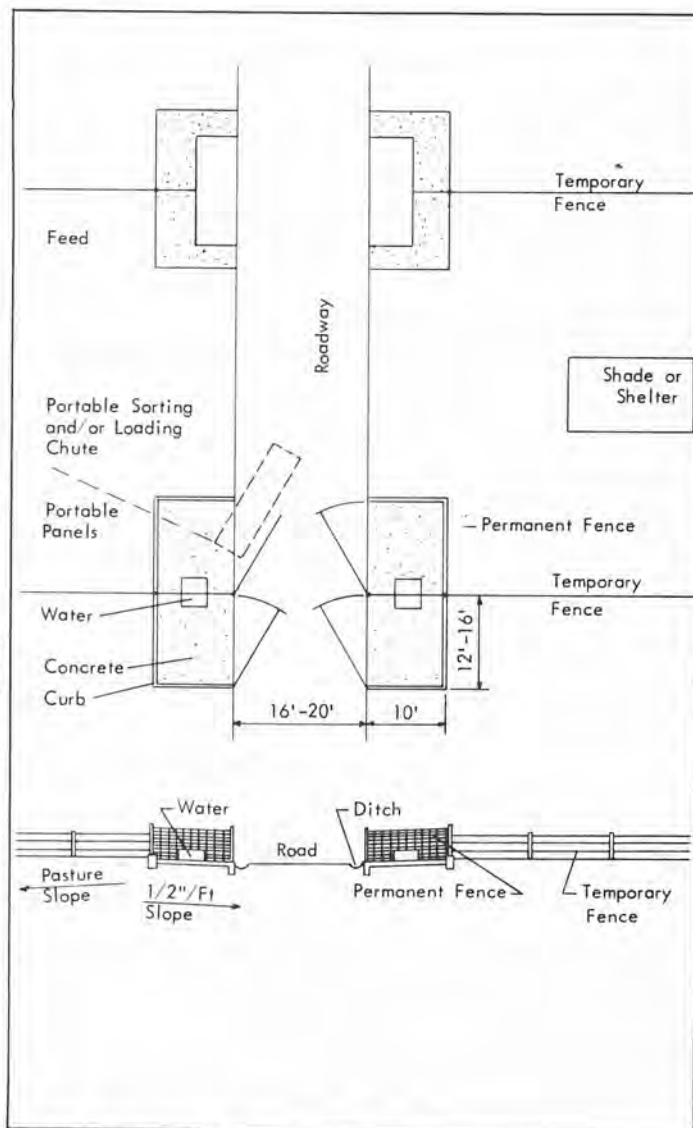


Fig 421-28. Layout for pasture facilities.

DIMENSIONS FOR SWINE*

SECTION 5—SWINE

5.2 Reference Points (See Fig. 15)

- L = Length from behind ear to base of tail
 H = Height from floor to top of back
 D = Depth from lowest point on belly to top of back
 W = Width at widest point near middle of hog. The width across shoulders and hams was found to be nearly equal to this dimension.

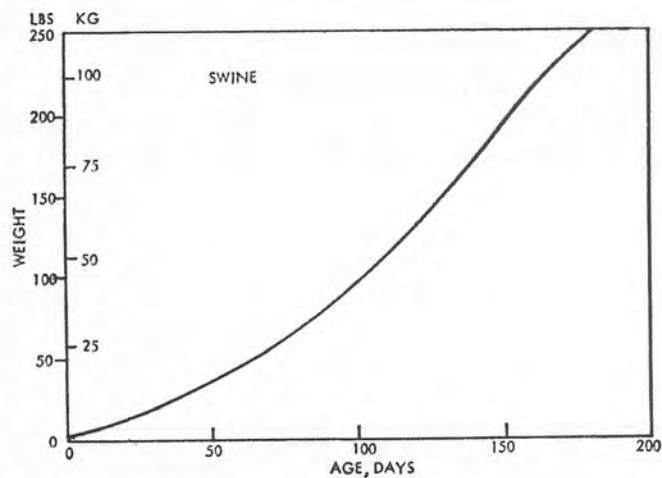
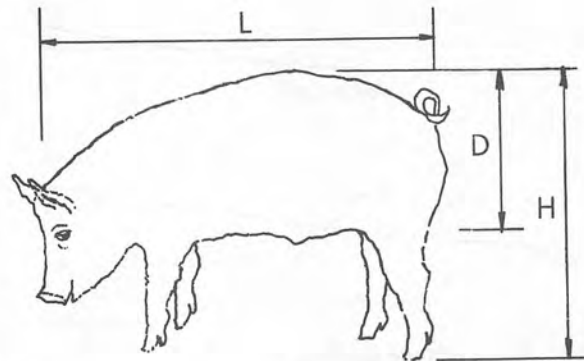


Fig 421-29. Weight versus age of swine.

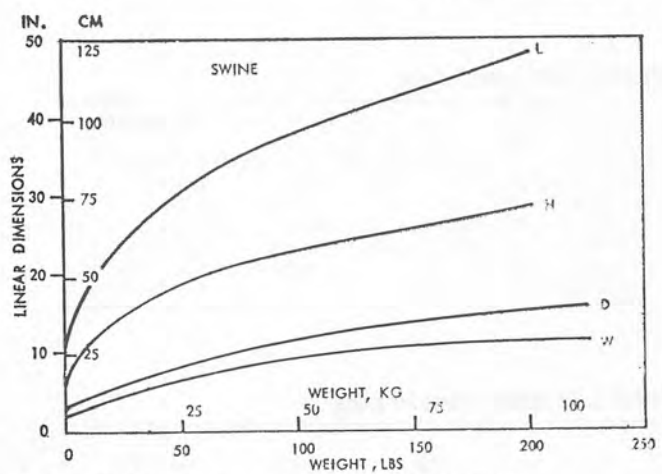


Fig 421-30. Physical dimensions versus weight of swine.

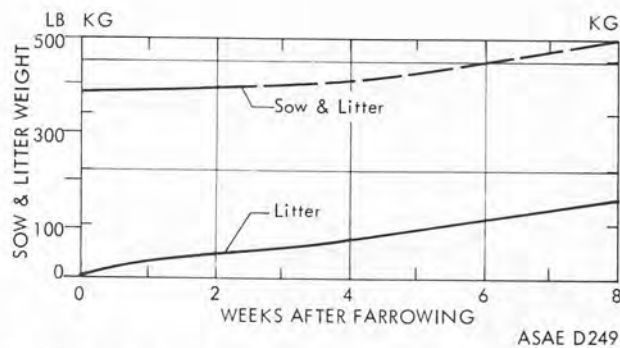


Fig 421-31. Weight of a sow and litter.

Table 421-2. Daily water for pigs.

Weight of Hog or Condition	Daily Water Consumption	
	lb	kg
30 lb (13.6 kg)	5-7	2.3-3.2
60 to 80 lb (27.2-36.3 kg)	7-10	3.2-4.5
75-125 lb (34.0-56.7 kg)	10-16	4.5-7.3
200-380 lb (90.7-172.4 kg)	12-30	5.4-13.6
Pregnant sows	30-38	13.6-17.2
Lactating sows	40-50	18.1-22.7

Table 421-4. Daily feed for swine.

Live Weight	Expected Daily Gain	Total Air-Dry Feed
lb kg	lb kg	lb kg
Growing finishing pigs		
10-25 4.5-11.3	0.6 0.3	1.2 0.5
25-50 11.3-22.7	1.0 0.4	2.5 1.1
75-125 34.0-56.7	1.6 0.8	5.2 2.4
125-175 56.7-79.4	1.7 0.8	6.7 3.0
175-225 79.4-102.0	1.9 0.9	7.8 3.5
Bred gilts and sows		
300 36.1	1.0 0.4	5.5 2.5
500 226.8	0.7 0.3	6.5 2.9
Lactating gilts and sows		
350 158.8	- -	11.0 5.0
450 204.1	- -	12.5 5.7
Young and adult boars		
300 136.1	1.0 0.4	6.0 2.7
500 226.8	- -	7.5 3.4

Table 421-3. Complete rations for swine.

Ingredient	Pig Starter		Pig Grower		Hand-Fed Gestation		Gilt Growing & Self-Fed Gest.		Lactation		50-75 lb (22.7-34.0 kg)		75-100 lb (34.0-45.4 kg)		150-200 lb (68.0-90.7 kg)	
	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Gr. yellow corn	1200	544.3	1500	680.4	1100	498.9	600	272.2	1200	544.3	1600	725.8	1700	771.1	1800	816.5
Gr. oat groats	200	90.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gr. oats	-	-	-	-	500	226.8	600	272.2	200	90.7	-	-	-	-	-	-
Alfalfa hay, wheat bran or midds	-	-	-	-	-	-	600	272.2	100	45.3	-	-	-	-	-	-
Pig supplement	600	273.1	500	226.8	-	-	-	-	-	-	-	-	-	-	-	-
All-purpose supplement	-	-	-	-	400	181.4	200	90.7	500	226.8	400	181.4	300	136.1	200	90.7
Total	2000	907.2	2000	907.2	2000	907.2	2000	907.2	2000	907.2	2000	907.2	2000	907.2	2000	907.2

*Extracted with permission from The 1969 Agricultural Engineers Yearbook. The American Society Of Agricultural Engineers, Box 229, St. Joseph, Michigan 49085.

CHAPTER 422 BEEF

General Procedure

Decide number of cattle, and feed and storage requirements.

Plan for future expansion. Feed storage and processing facilities are likely to be expanded, rather than duplicated. Feed bunks and buildings may be enlarged, but often whole lots are duplicated. Paving lots may permit doubling or tripling the number of head if adequate feeding and watering facilities can be arranged. It is wise to provide generous facilities during new construction to permit early increase in cattle numbers.

Compute the areas needed.

Select a site, with special attention to drainage and waste disposal.

Sketch tentative layouts. Establish traffic routes for animals, cleaning equipment, supply trucks, etc.

Compare several trial layouts with the recommendations given. Any layout will require compromises.

Select the type of facilities:

Feedlot: Cattle are confined to lots. They may be provided with no shelter, other than wind protection (trees, topography, or wind-fences). Shelter may be provided in an open-front building. Bedded area may be inside with feeding outside, vice versa, or some combination.

Cold* Confinement: Cattle are confined within a building which is more or less open, so that winter conditions are within a few degrees of outdoor temperatures. Natural ventilation is usually sufficient.

Warm* Confinement: Cattle are confined within a building which is sufficiently insulated and ventilated to maintain inside winter conditions above 35°F in severe weather and in the range of 50° to 70°F most of the time.

*Note that "Cold" and "Warm" refer to winter conditions; without mechanical cooling, both systems are "Warm" during summer months.

A feedlot and its site must be designed together. The layouts on these three pages, and the comments about them, illustrate some ways in which the required facilities can be combined.

Lot Space Requirements

Table 422-1. Total space required per animal.

Sq ft per Head Min.	Lot Type and Condition
400	Lot unsurfaced
150	Lot partially surfaced (includes indoor feeding with outdoor resting)
55	Lot surfaced, no shelter
30	Lot surfaced, with open housing

Data Summary

Space Requirements

Lot Area Sq Ft/Head

- 400 lot unsurfaced
- 150 lot partially surfaced
- 55 lot surfaced, no shelter
- 30 lot surfaced, with open housing

Resting Area In Sheds or Under Shade

- 25 to 30 sq ft for mature cows
- 20 to 25 sq ft for feeders 600# to market
- 15 to 20 sq ft for calves to 600#

Corrals

- Holding pens, 20 sq ft per mature animal
- Crowding pen, 150 sq ft or one truckload
- Working chute, 18 to 30 sq ft
- Sorting alleys, 10 to 12 ft wide

Feeding Space

- When all animals eat at once
- 18" to 22", calves to 600#
- 22" to 26", 600# to market
- 26" to 30", mature cows

Feed Always Available

- 4" to 6", hay or silage
- 3" to 4", grain or supplement
- 6", grain and silage

Watering

- 40 head per water space in drylot
- 15 gal/head/day, 5500 gal/year

Bunk Dimensions

Throat Height

- Up to 18" for calves, 22" for feeders and mature cows. Use 30" height only if hogs will run with cattle.

Widths

- 48" if fed from both sides
- 54" to 60" if bunk is divided by mechanical feeder
- 18" bottom width if fed from one side

Concrete Apron Along Bunk

- 1"/ft slope, self cleaning
- ½"/ft slope, min.; add 4" to 6" high and 12" to 16" wide step next to bunk
- 4" to 6" thick
- 6' to 12' wide

Fences

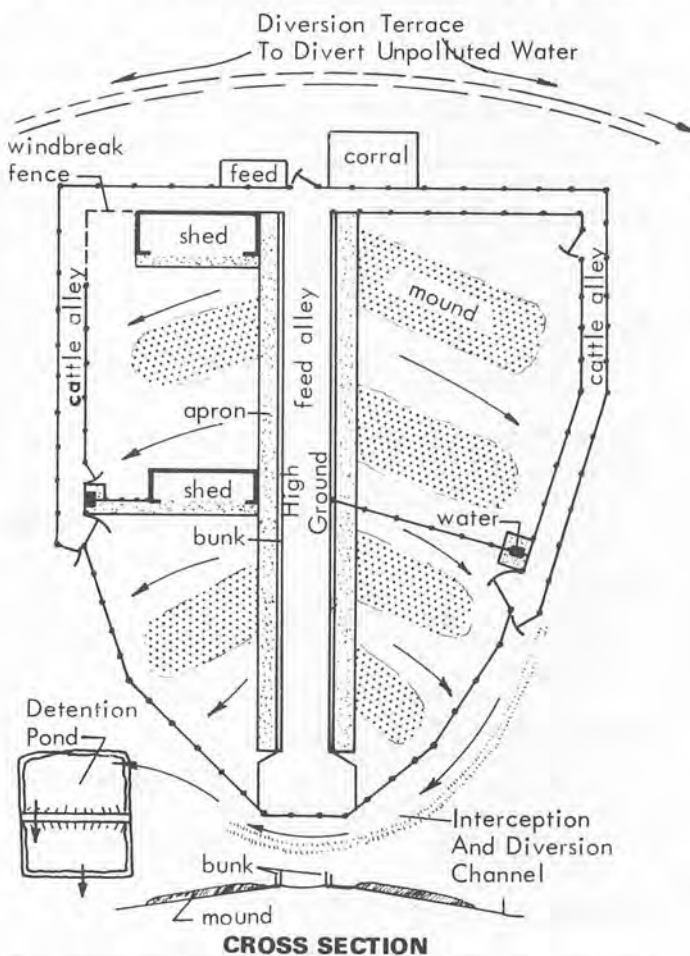
	Line	Feedlot	Working
Post length	7'	9'	10'
Depth of set, approx	2½'	4'	4'
min	2'	3'	3'
Post spacing	1 rod	8'	6'

Topography, Drainage

Slope outdoor lots a uniform 4% to 6% away from winter prevailing winds, usually south or east. Unpaved lots having slopes over 10% may erode. A slight north or west slope can usually be graded to a 4% south or east slope. Consider moving from present lot site to obtain desirable slope. Complete land grading before starting construction.

Use road ditches or terraces as drainageways to intercept uphill water. Slope lots away from buildings and feeding lines. Avoid drainage from one lot to another. Install eave troughs and drains on sheds. Crown unsurfaced roads.

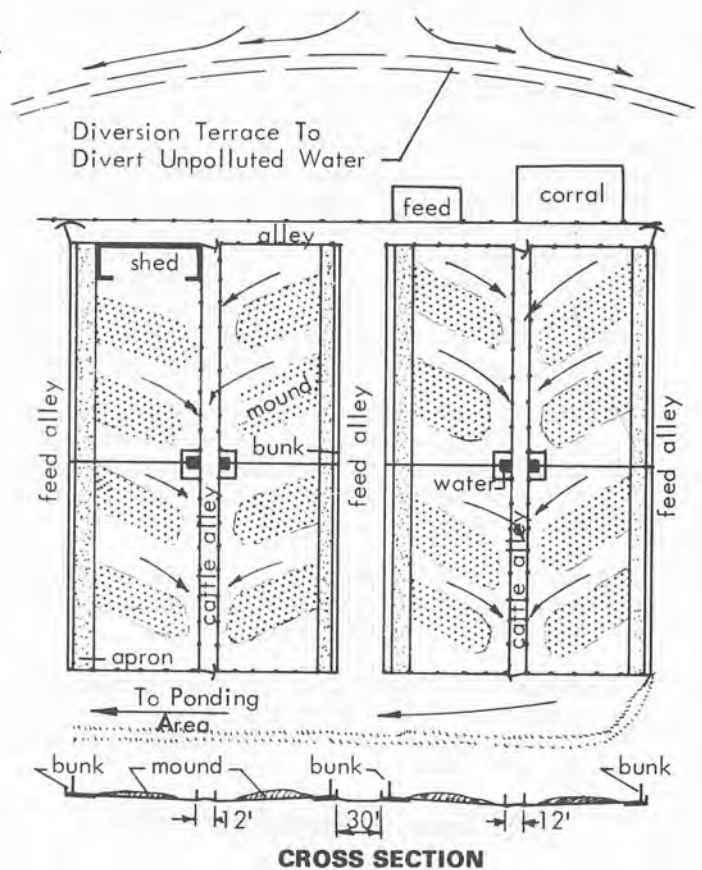
Orient **Feeding Lines** to provide best drainage—either at the high side of the lot or up and down the slope. When compatible with drainage (a year-round problem), N-S or NW-SE orientation is generally preferred, because the sun can melt ice and dry the pavement along both sides of the bunk.



The arrows in the plan above show the direction of drainage.

Fig 422-1. Layout showing drainage pattern for lots at end of N-S ridge, or "hog-back".

The Cross Section shows the lots sloping away from the feed alley on the ridge; mounds built up to provide dry areas in unpaved lots. Sheds, if provided, may be located as shown.



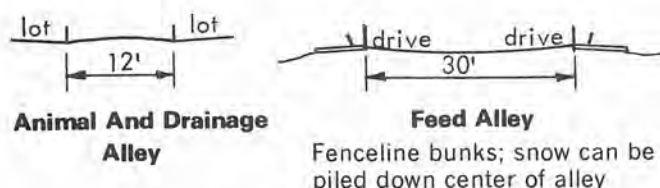
The arrows in the plan above show the direction of drainage.

Fig 422-2. Layout showing drainage pattern for lots along a uniform south slope.

The Cross Section shows how grading provides relatively high ground at the bunks and mounds, and lower ground at the cattle alleys to provide drainage down the slope to detention ponds.

Traffic Routes

Vehicles and cattle require alleys at least 12' wide. Roads between two parallel fenceline bunks may be 30' wide, troughed to the center, to provide drainage and space for plowed snow.



Lot Pavement

Pave heavy traffic areas, around water, and along feed lines. Additional pavement may pay for itself if cattle would otherwise be in mud for extended periods. Concrete has generally been the most satisfactory paving material.

Slope all aprons along bunks, sheds, and waterers 1" per foot.

Storage-Processing

Locate feed center convenient to feeding area, and away from cattle traffic patterns. Avoid blocking summer breezes. Consider snow drifting. Silos behind a shed tend to cause snow drifts inside it. Provide all-weather access roads.

Shadows

Locate structures to avoid continuous shadows in the lot, especially in freezing climates. Snow and frozen manure will accumulate on the north side of buildings, bunks, silos, etc.

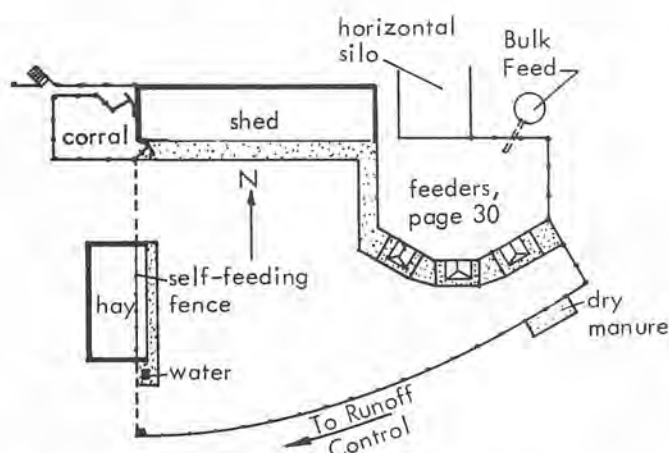


Fig 422-3. A layout for a small enterprise.

It includes drainage, manure handling, an automatic waterer on concrete, and a simple cattle handling system. Pavement in front of the shed and along animal traffic routes is recommended.

Housing

Face the long, open side of sheds away from prevailing winter winds usually east or south. Provide doors or other openings in the closed walls for summer ventilation. Provide eave troughs or paved splash aprons. Unpaved floors should be at least 12", and paved floors at least 6" above outside grade. Slope floors toward open sides of shed.

Feedlots without shelter are most common in feeder operations in drier and milder climates, and in minimum facilities for cow-calf operations in drier, though perhaps cold, climates.

The addition of a building is generally common in colder, wetter, and windier climates. Limited research to date indicates that in such climates at least minimum housing will be paid for in gain efficiencies.

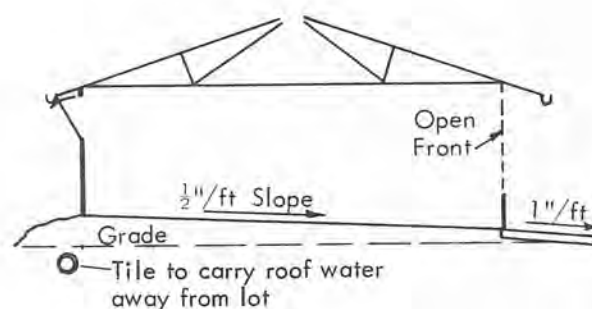


Fig 422-4. Open front building.

Advantages of Buildings

Covered feed bunk:

- Protects feed and equipment from rain and snow.
- Can provide summer shade.

If in building, also prevents feed from blowing from bunks, and encourages eating during severe weather.

Open front building in feedlot:

- Provides shade, winter shelter, bedded area.
- Can be converted to confinement.

Resting

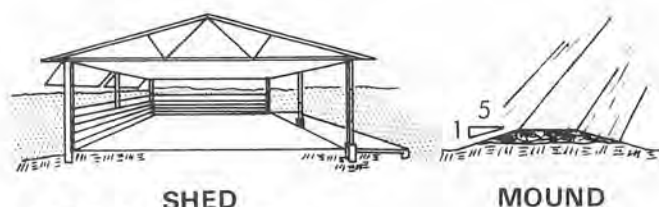


Fig 422-5. Two types of resting areas.

Cattle require a dry resting area, either in a shelter or on a well-drained, bedded mound.

Allow: 25 to 30 sq. ft. for mature cows.

20 to 25 sq. ft. for feeders 600# to market.

15 to 20 sq. ft. for calves to 600#.

Lots

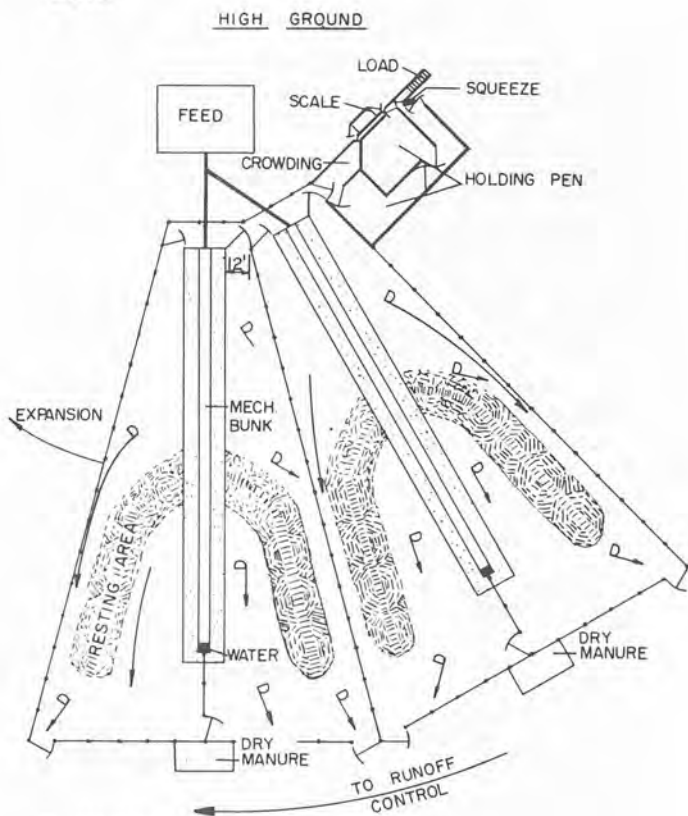


Fig 422-6. Pie shaped lots.

Mechanical feed bunks arranged in a pie shape suggest a large enterprise with a feed-processing center capable of considerable expansion.

If mound resting areas are used, as illustrated, covered bunks can provide some shade. Sheds could be placed along the division fences, although some openings would face prevailing winds.

Note that cattle and feed handling traffic require relatively short roadways.

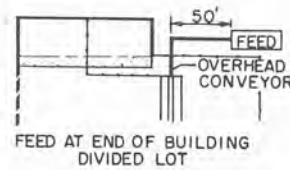
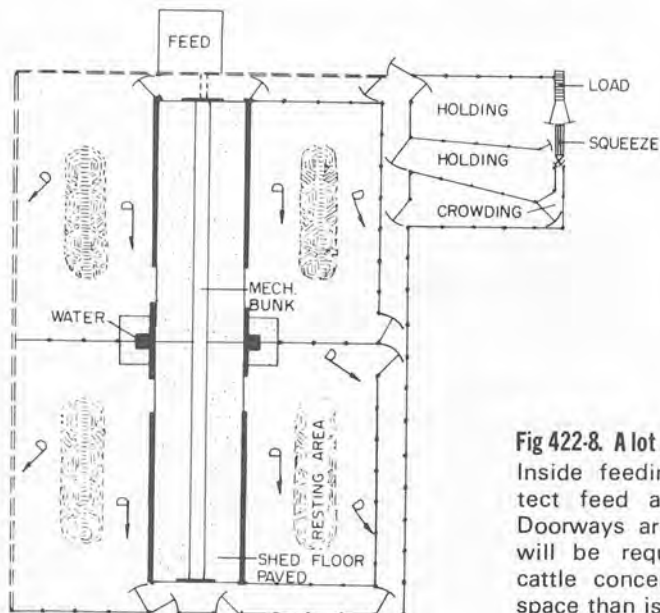
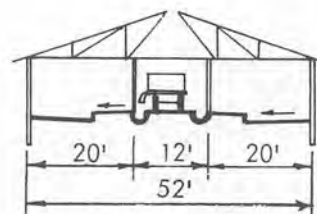
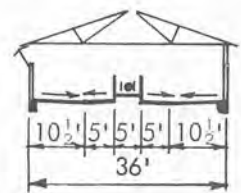


Fig 422-7. Lot divided by mechanical bunk.

A single, mechanical bunk divides this lot. Note that a passage is provided at each end of the bunk. Steers on a finishing ration may be moved into a separate lot.



Feed-Wagon Distribution



Mechanical Conveyor Distribution

Fig 422-8. A lot with indoor feeding.

Inside feeding (outdoor resting) is suitable for northern regions to protect feed and equipment, and to provide shelter in severe weather. Doorways are indicated for cattle access, although additional openings will be required for summer ventilation and power cleaning. Heavy cattle concentrations may require some outside paving, or more total space than is illustrated.

Cold Confinement

Natural year-round ventilation

Cold Confinement has been introduced to solve problems in dry-lots caused by drifting snow, severe wind and mud, and to aid in control of wastes. Both bedded and liquid manure systems are being used, depending primarily on the local cost and availability of bedding, and labor available for cleaning.

Cold (refers to winter) Confinement—comments

- Lower cost than warm confinement.
- With liquid manure handling, more suited to areas without extended periods of very low temperatures.
- Natural ventilation adequate except during extended high-temperature periods with no wind.

Space Required

30 sq ft per 1000# animal on solid floors, or 20 sq ft per 1000# animal on slotted floors, plus feeders and alleys.

Warm Confinement

Fan ventilated in winter;
fan or natural ventilation in summer

Warm Confinement has the advantage over open housing of temperature control during cold weather—less freezing of manure and equipment, and more comfort for the operator. Supplemental heat may be required if moisture is to be controlled during cold weather.

Warm (refers to winter) Confinement—comments

- Insulation and fan ventilation control indoor conditions during coldest weather, reducing temperature fluctuations and animal stress.
- Manure build-ups on aprons or slats are avoided in severe weather.
- Fan or natural ventilation may be used in summer.

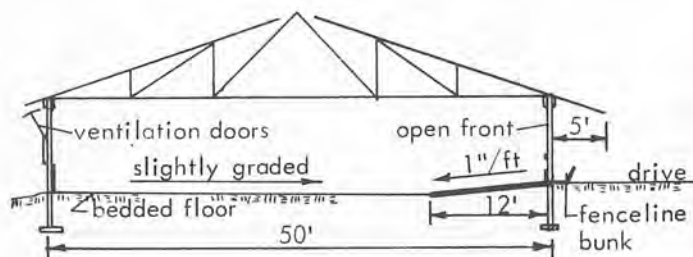
Space Required (no bedding, solid or slotted floors):

20 sq ft per 1000# animal, plus feeders and alleys.

COLD CONFINEMENT

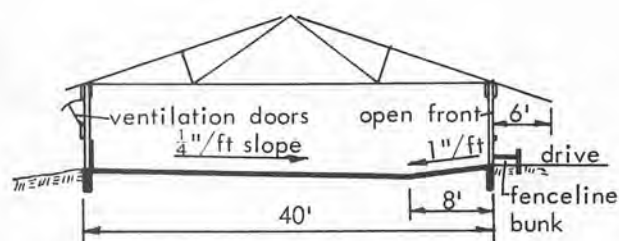
Fig 422-9. Two buildings with fenceline bunks; bedded.

Solid Manure Handling: Clean apron often; clean bedded area 3 to 4 times per year.



A 50' building has room for 1.7 animals per foot of length. This limits bunk space per animal and therefore requires more frequent feeding.

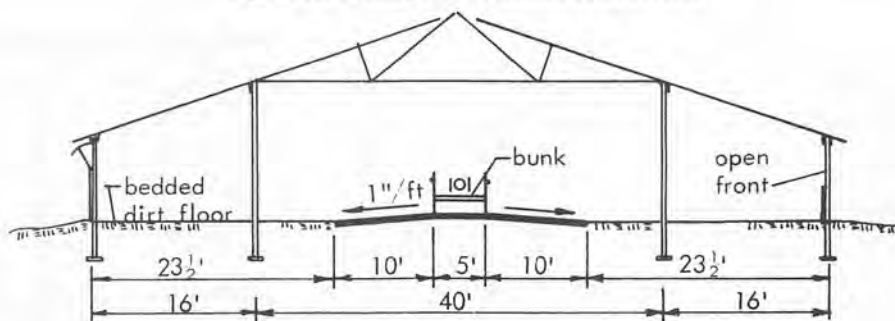
(Michigan State University)



A 40' building has room for about one animal per foot of length.

(University of Minnesota)

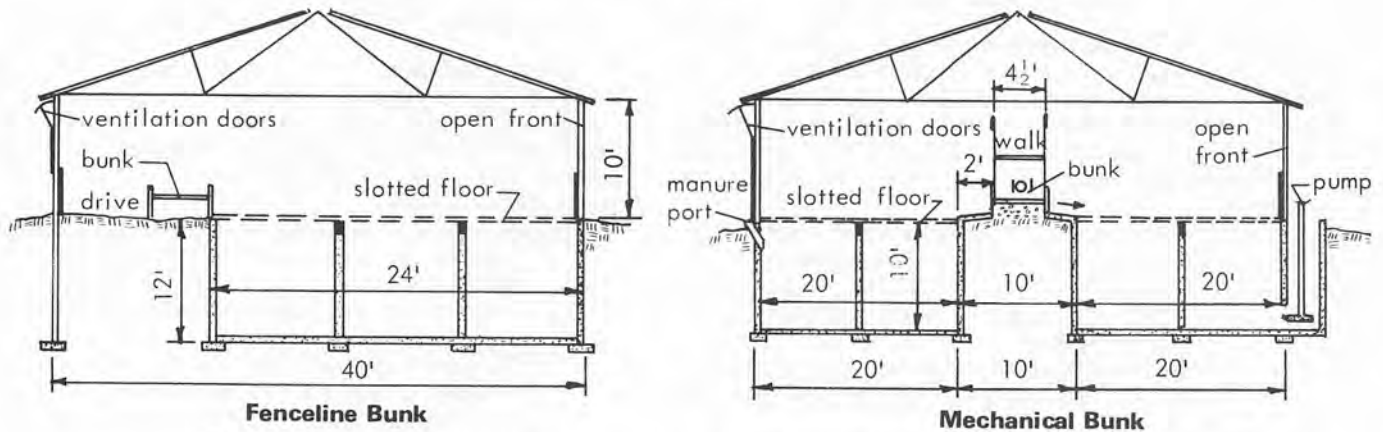
Fig 422-10. Building with mechanical bunk; bedded.



This 72' building has room for 2 1/3 animals per foot of length. Exhaust fans may be needed in the end wall for improved winter and summer ventilation.

(Michigan State University)

Fig 422-11. Confinement buildings with slotted floors.



Fenceline and mechanical bunk sections for slotted floors and liquid manure handling. Provide annex or ports for manure stirring and pumping. NOTE: Insulation and fan ventilation may be added to these "open" units for operation in severe climates.

(Iowa State University)

WARM CONFINEMENT

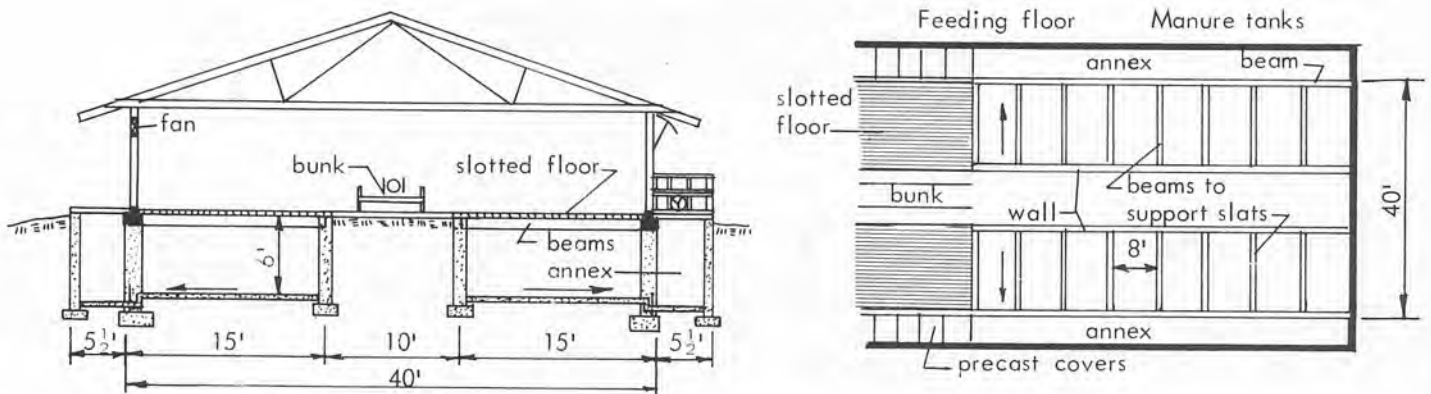


Fig 422-12. Warm confinement building with slotted floor.

Slotted floors except at bunk, with annexes along both sides of the building for liquid agitation and removal. Year round fan ventilation suitable for severe climates.

(University of Minnesota)

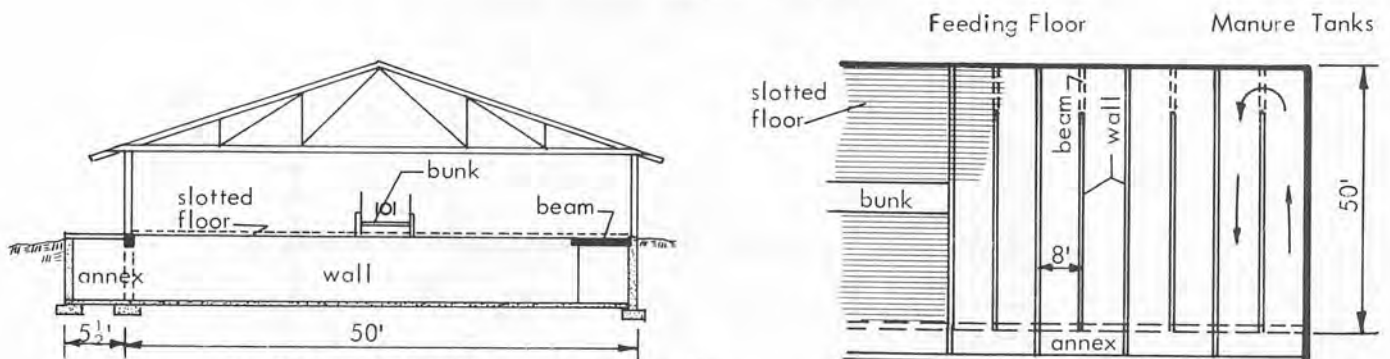


Fig 422-13. Total slotted floor; annexes along one side.

Slotted floors with annexes down one side of building. Each manure compartment is 16' x 54' with a dividing wall to support slats and to form a channel for manure circulation.

(University of Illinois)

Minimum Working Corral

Holding Pen, 20 sq ft per mature animal.

Crowding Pen, 150 sq ft or one truckload.

Working Chute, 18 to 30 ft long, 26" max. bottom width headgate.

Loading Chute, 30" to 42" wide.

Useful Features

Additional holding pens.

Blocking Gates—prevent crowding at scale, cutting gates, spray area, or squeeze.

Cutting Gates—separate animals by weight, age, health, etc.

Squeeze—restricts animal more than headgate, for veterinary services; required for branding.

Scale—either large platform for truck or stock, or portable, for use in working chute.

Spray Pen—8'x30' for one carload; crowding pen may be used or dipping vat.

Sorting Alley—10' to 12' wide.

Provide water in lots for holding cattle overnight.

Provide for feed and water in one holding pen to be used as bull pen.

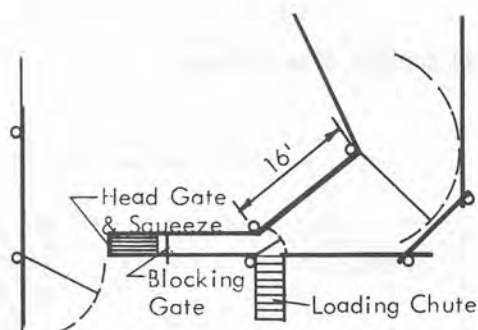


Fig 422-14. Corral with funnel crowding pen.

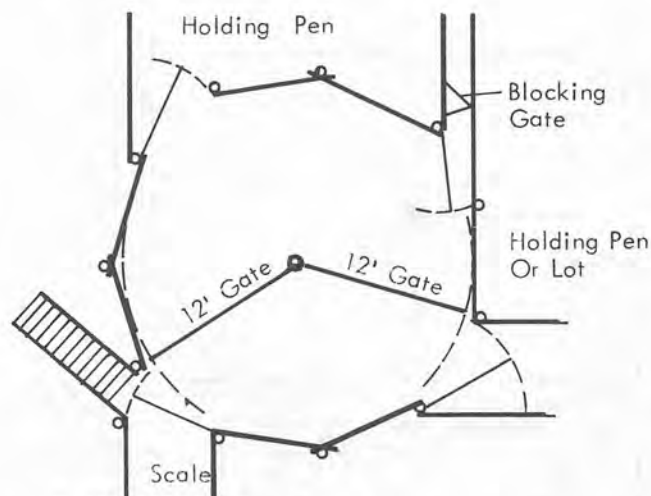


Fig 422-15. Circular crowding pen.

Positive Crowding, More Difficult To Construct, Less Useful For Other Purposes.

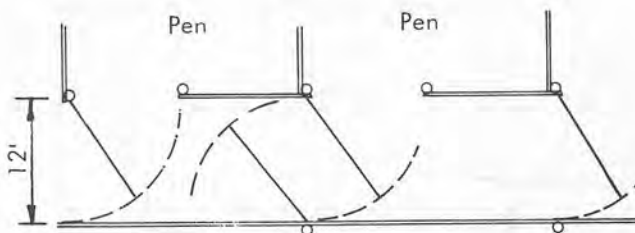


Fig 422-16. Sorting alley.

With Cross Gates, Can Be Used For Spraying & Holding

Simple Layouts

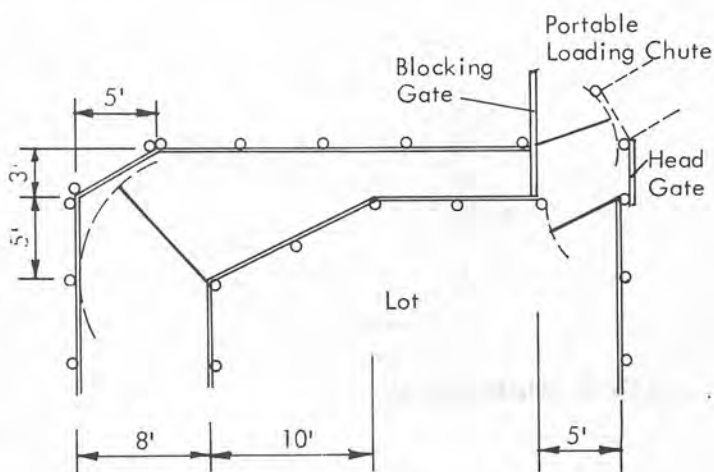


Fig 422-17. Sorting alley in corner of lot.

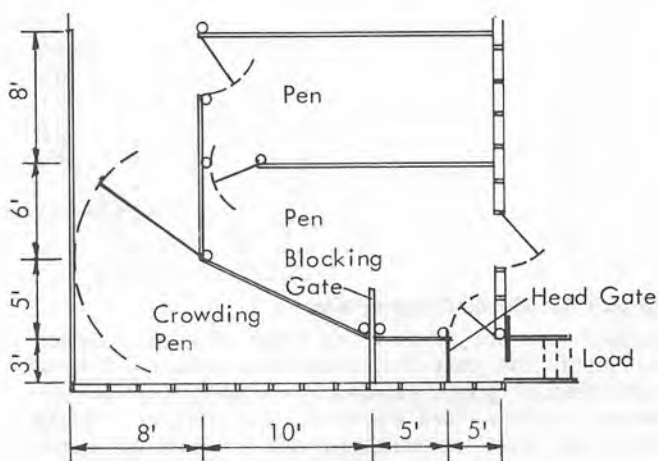


Fig 422-18. Crowding pen in barn corner.

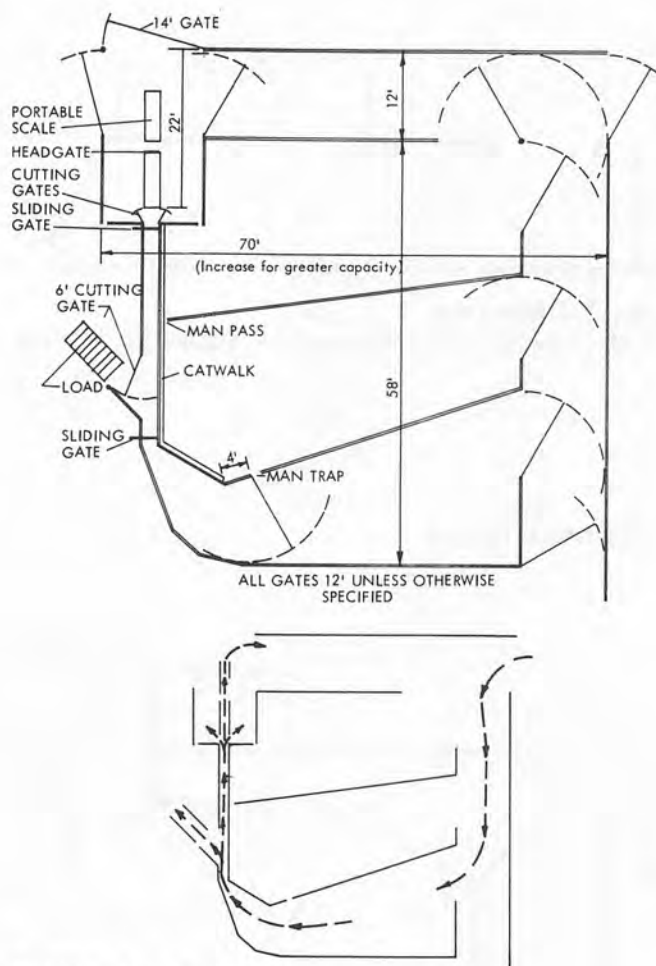
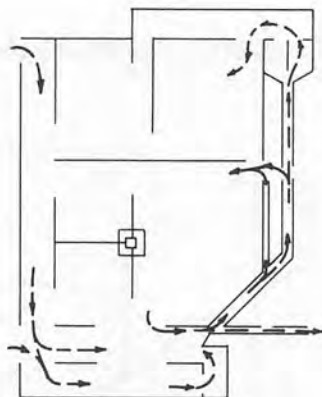


Fig 422-19. Corral for 200 head.



Layout For Cattle Dipping Vat

Dipping vats are suitable for larger operations which can justify the cost of the vat, relative to the cost of high-pressure spray equipment. Dipping controls external parasites more positively than spraying, unless very good spraying equipment and practices are used.

Grade around the vat to divert all surface run-off.

Dispose of used dip only after completely following the chemical manufacturers' detoxification recommendations.

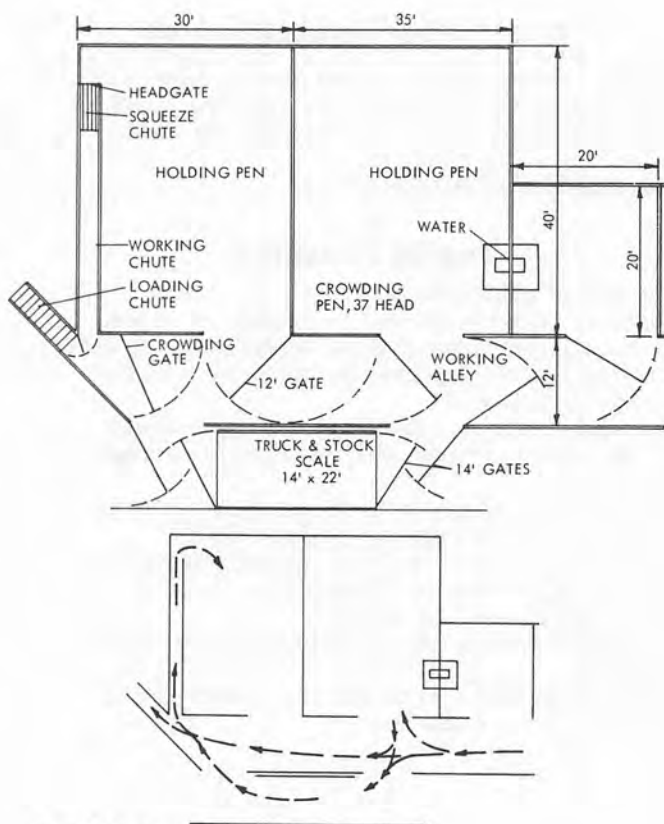


Fig 422-20. Corral for 200 head or more.

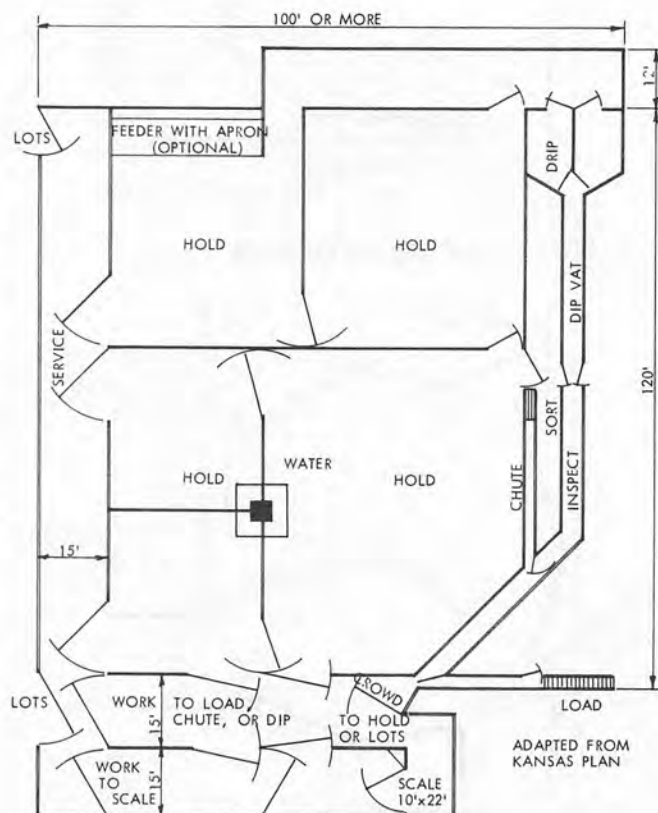


Fig 422-21. Corral for 600 head or more.

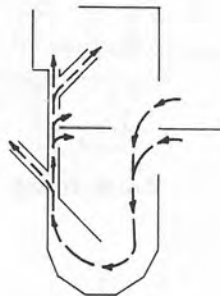
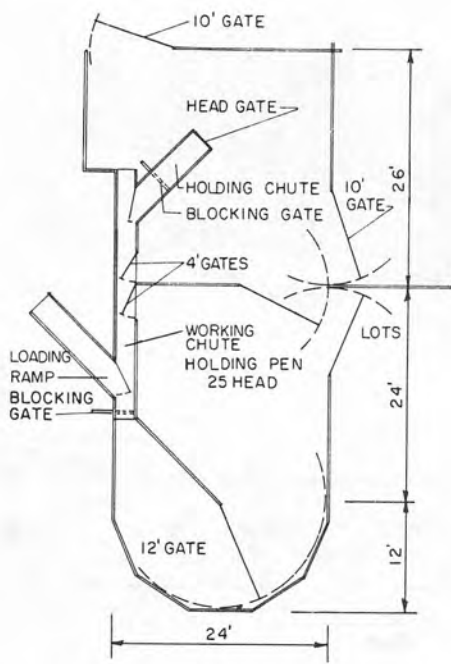


Fig 422-22. Corral for 100 head.

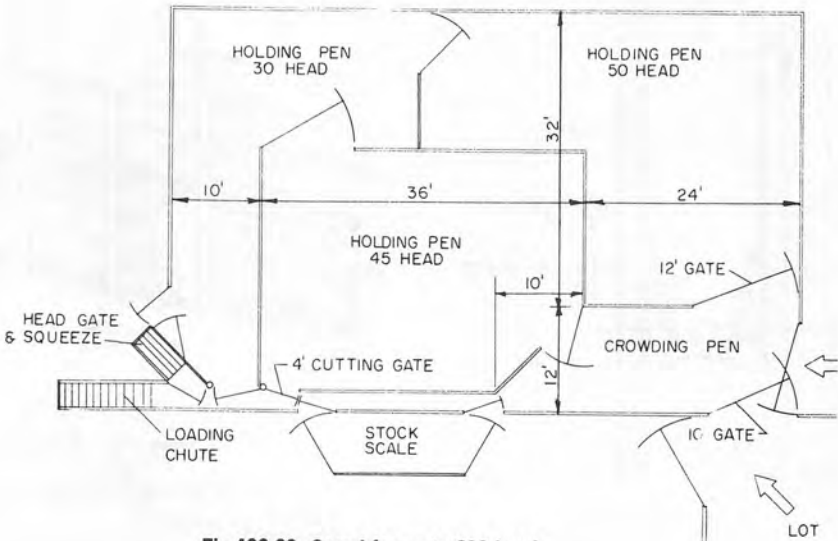


Fig 422-23. Corral for up to 200 head.

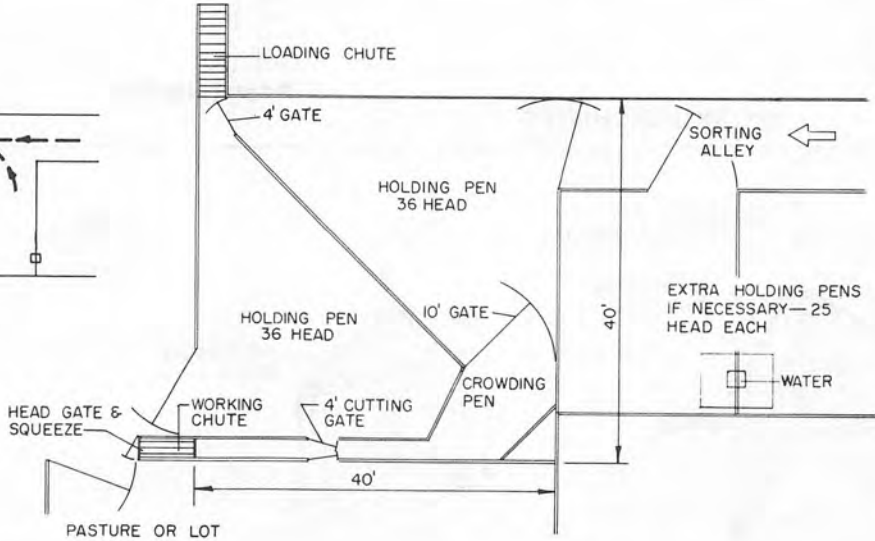
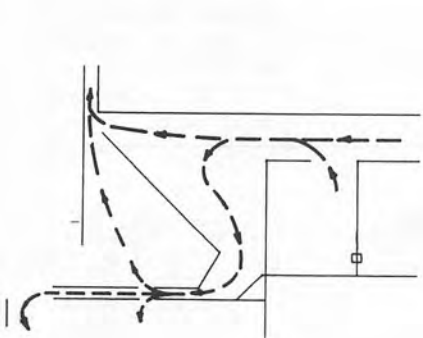
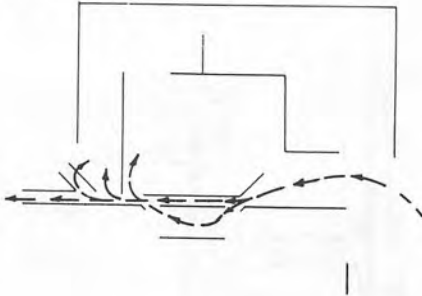


Fig 422-24. Corral for 100 head or more.

Fig 422-25. Typical construction of working chutes.

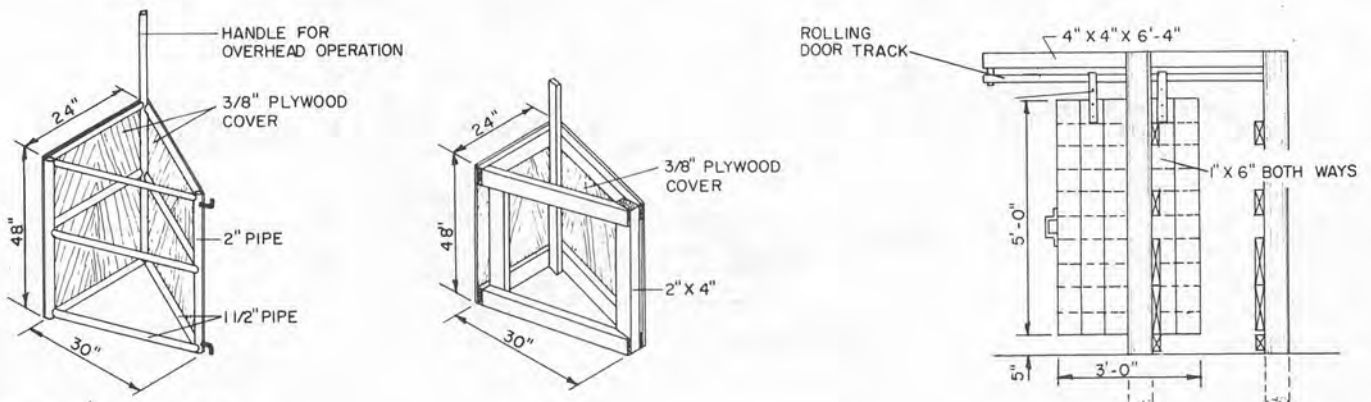
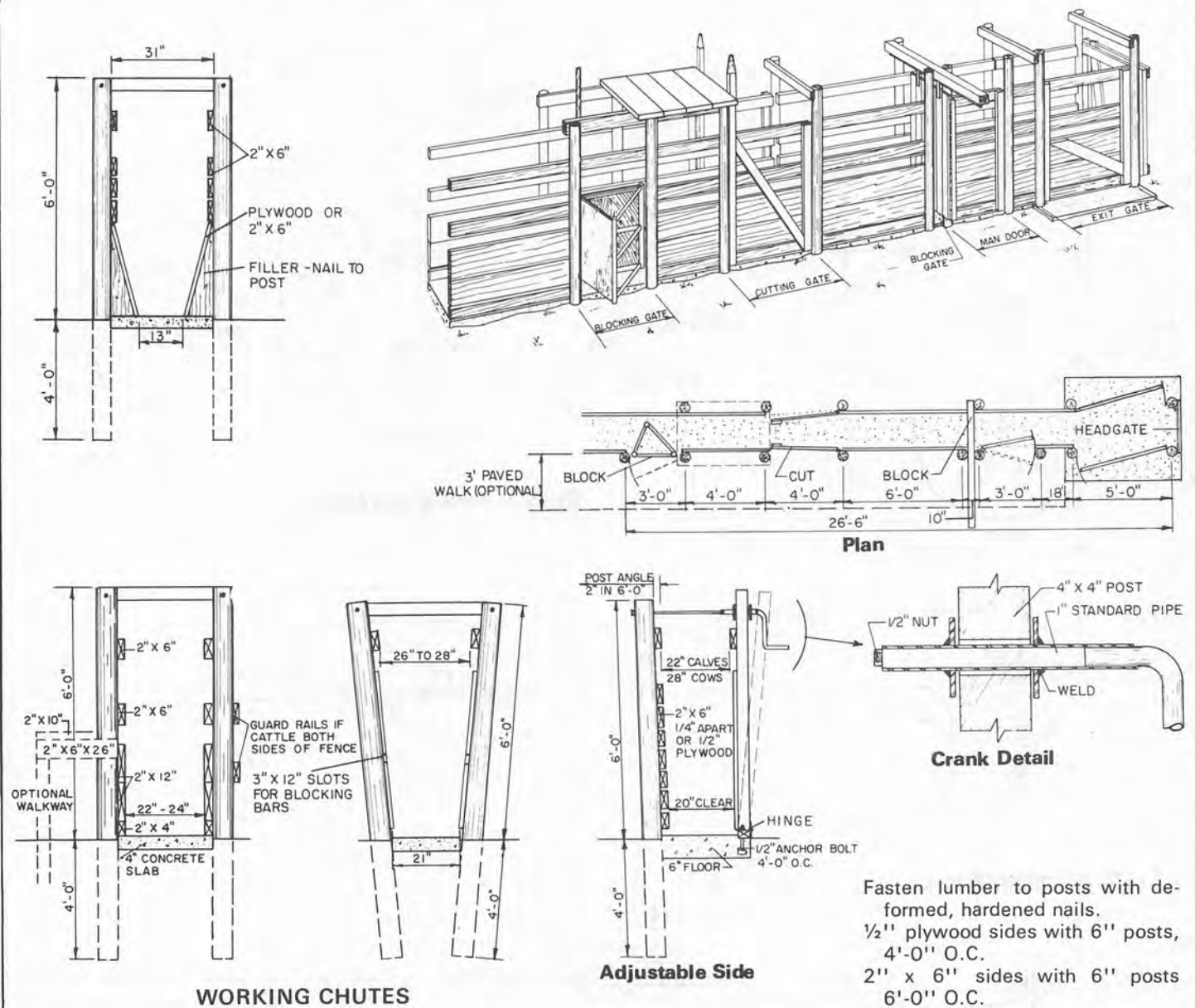


Fig 422-26. Blocking gate details.

Feeding

Feeding space per animal is determined by the size of the animal, and the number of animals which will eat or drink at one time.

If all animals must eat at the same time, allow: 18"-22" per calf up to 600 lbs; 22"-26" per animal from 600 lbs to market; and 26"-30" for each mature cow.

If feed is always available allow 4"-6" per head for hay or silage; 3"-4" per head for grain or supplement; and 6" per head for grain and silage.

Watering

Drylot—40 head per waterer space. Locate waterers where they are easily accessible. Pave at least a 10' apron around waterers.

A minimum of 15 gallon per head per day should be supplied (5,500 gallon per year).

Mechanical Bunks

Cattle are usually fed from both sides. The bunks can serve as lot dividers. The feed center must be near the feeding line.

Width of Bunks

- 48" if fed from both sides
- 54"-60" if bunk is divided by mechanical feeder
- 18" bottom width if fed from one side of bunk

Throat Height

- Up to 18"—calves
- 22"—feeders and mature cows
- 30"—only if hogs will run with cattle

Fenceline Bunks

Cattle are fed from one side. The bunks are usually filled with a power unloading wagon or truck. They can be used with any size of operation and are easily lengthened. Feeding drives take a lot of space, and must be surfaced for all-weather use. Twice as much total bunk length (but not twice as much cost) is required as for bunks where cattle feed from both sides.

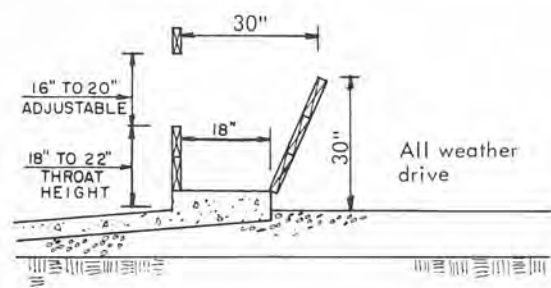


Fig 422-27. Fenceline bunk dimensions.

Where frozen manure, etc may collect.
Adaptable to any age of stock.

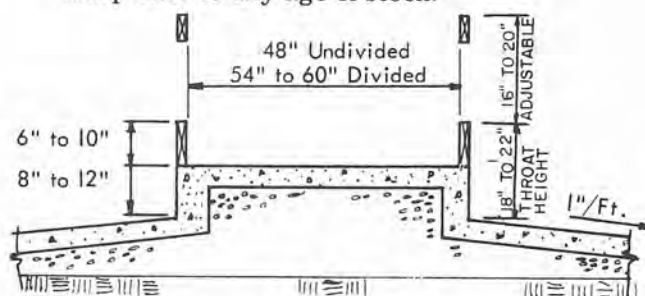


Fig 422-30. Dimensions for bunk with raised floor.

BUNK DESIGN

Apron

An apron sloped 1" per foot will control surface water, will have little manure accumulation near the bunk, and will discourage bunk fouling. A 1/2" per foot slope is minimum.

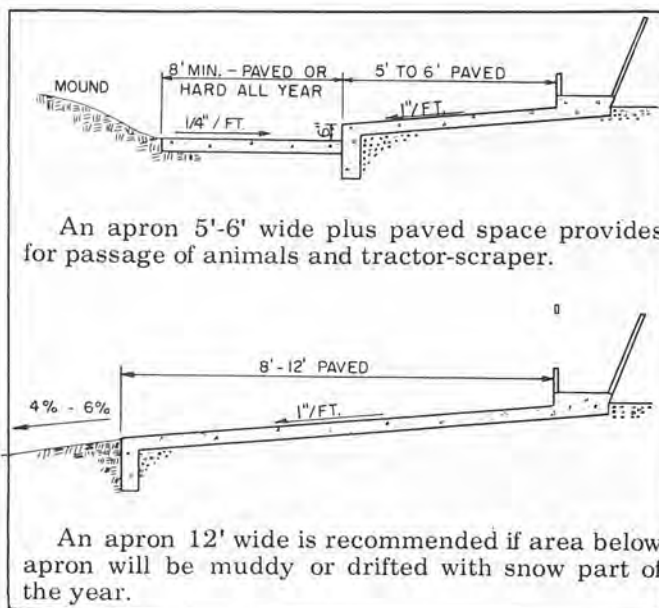


Fig 422-28. Dimensions for aprons.

Where apron is kept scraped.
Least cost, easiest to build.
Adaptable to any age of stock.

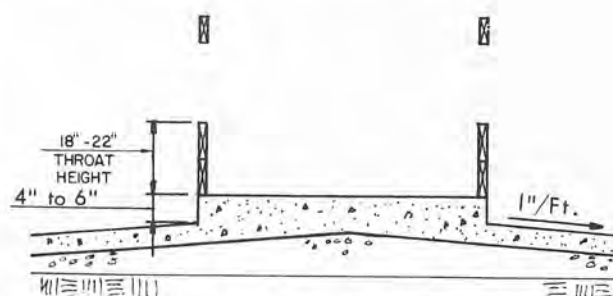


Fig 422-29. Dimensions for bunk with low floor.

High Floor

When bunks are added over an existing flat pavement, increased height is sometimes recommended.

Most expensive.

Conventional dimensions in flat, unscrapped lots.

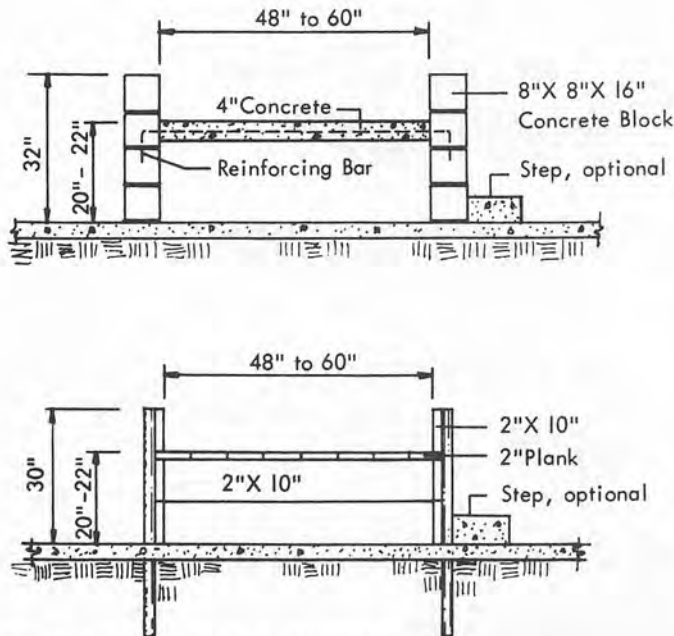


Fig 422-31. Dimensions for bunk with high floor.

Covered Bunks

If feed is to be in a bunk for extended periods, weather protection is advisable.

A narrow roof 5'-6" above apron will provide protection of bunk and give minimum shade.

A wide roof high enough to clear cleaning equipment provides shelter for feed and cattle, and summer shade. A wide roof may cause additional snow drifting and may prevent thawing unless oriented about NNE-SSW.

Some cattlemen object to cows resting on the paved apron and so provide no shade over the bunk.

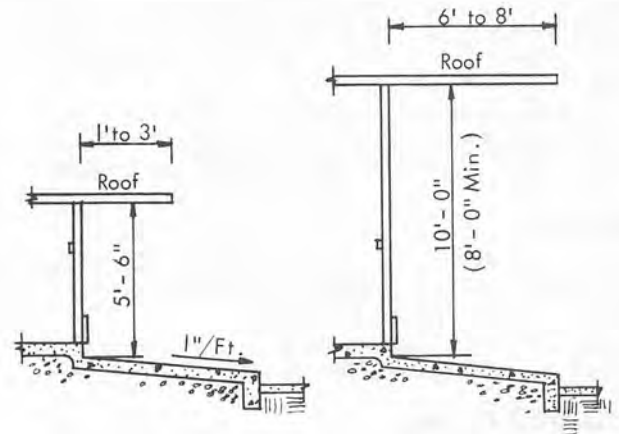


Fig 422-32. Roof dimensions for covered bunk.

A step next to the bunk, especially on aprons with little or no slope, will help keep the bunk clean by preventing the cattle from standing along the bunk or backing up to it. Steps protect a bunk from scraping equipment, especially with outside posts. With high-floor bunks, steps reduce throat height.

Install a step on flat (solid or slatted) floors. Optional if apron slopes 1" per foot.

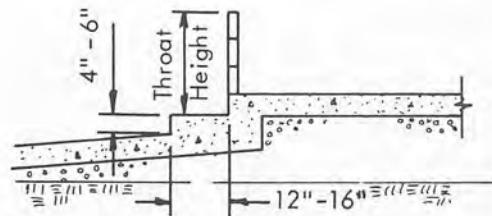


Fig 422-33. Bunk step dimensions.

Dimensions for Beef *

SECTION 3—BEEF

3.1 Weight versus age is shown in Fig. 5. Physical dimensions versus weight are shown in Fig. 6. The data were obtained from three dimensional photographs taken of 68 steers of mixed European-type beef breeds at various stages of growth from about 150 lb (68 kg) to about 1300 lb (590 kg).

3.2 Reference Points (See Fig. 6)

Point	Description
25	Length coordinate, $X = 0$ Rear tangent of the animal
1	Height coordinate, $Y = 0$ Floor
12	Thickness coordinate $Z = 0$ Center of back over shoulder. X coordinate not definite
2	Thickest point of hindquarter
6	Center of back above hindquarter. X coordinate not meaningful
8	Bulge of the belly
10	Bottom of chest highest above ground
11	Thickest point of shoulder
14	Pronounced break in brisket. Not accurately located
20	Center of foreleg at knee
21	Center of foreleg at dew-claw
22	Center of rear leg at dew-claw
23	Center of rear leg at hock.

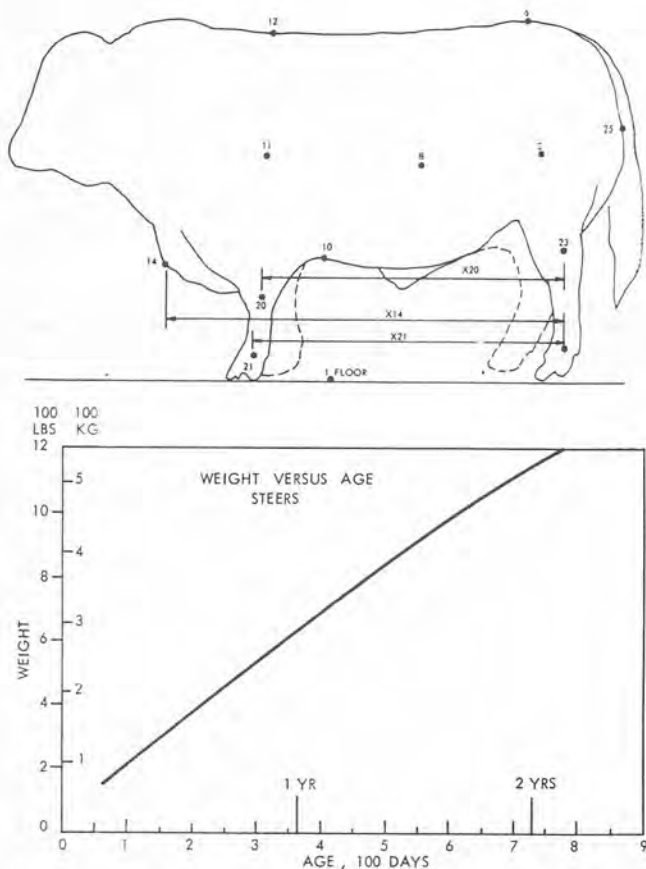


Fig 422-34. Weight versus age of steers.

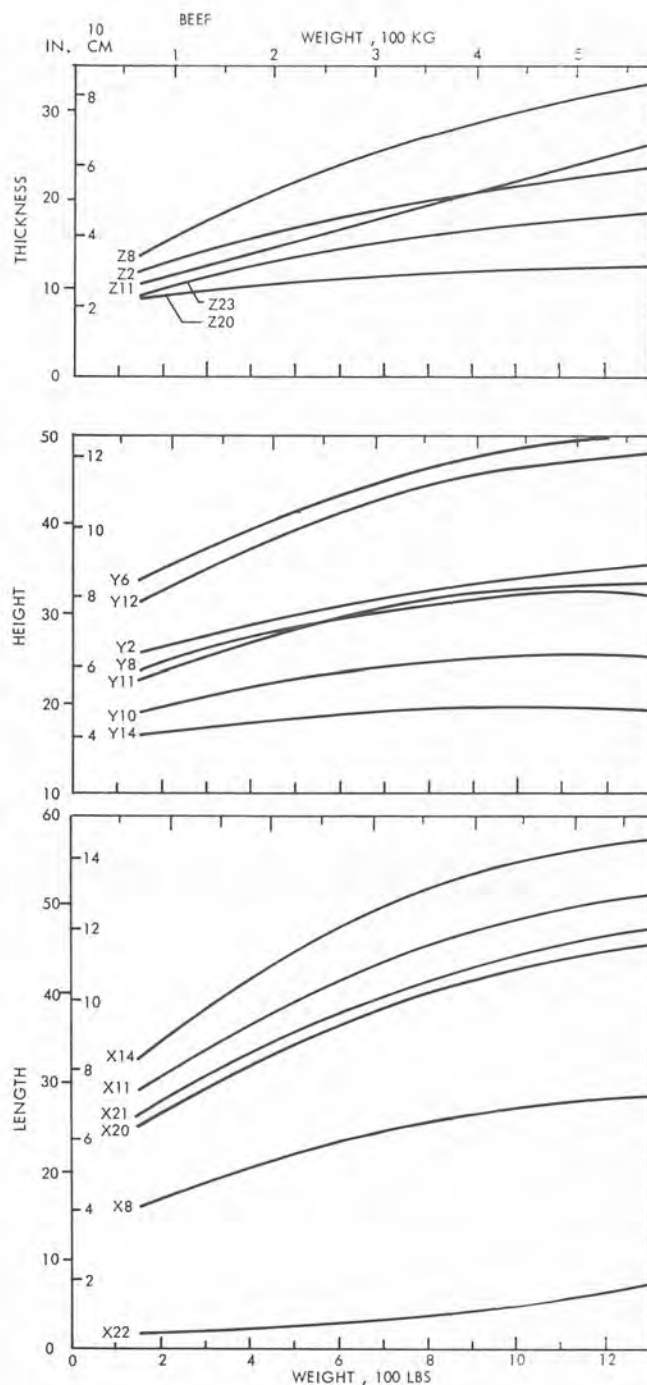


Fig 422-35. Physical dimensions versus weight of steers.

Table 422-2. Daily feed for beef cattle.

Body Weight		Avg Daily Gain		Daily Feed per Animal		Total Protein	
lb	kg	lb	kg	lb	kg	lb	kg
Wintering pregnant heifers							
700	317	1.5	0.7	20.0	9.1	1.5	0.7
900	408	0.8	0.4	18.0	8.2	1.4	0.6
1000	453	0.5	0.2	18.0	8.2	1.4	0.6
Wintering mature pregnant cows							
800	363	1.5	0.7	22.0	10.0	1.7	0.8
1000	453	0.4	0.2	18.0	8.2	1.4	0.6
1200	544	0.0	0.0	18.0	8.2	1.4	0.6
1200	544	-0.5	-0.2	17.6	8.0	1.3	0.6
Cows nursing calves, first 3-4 months postpartum							
900-	408-						
1100	499	0.0	0.0	28.0	12.8	2.3	0.1
Finishing yearling cattle							
600	272	2.6	1.2	17.5	7.9	1.8	0.8
800	363	2.7	1.2	22.3	10.0	2.2	1.0
1000	453	2.6	1.2	25.8	11.7	2.6	1.2
1100	499	2.3	0.1	25.8	11.7	2.6	1.2

Table 422-3. Daily water for beef cattle.

Daily Water Consumption At Various Ambient Temperatures							
Weight of Beef Cattle		50 deg F (10 deg C)		70 deg F (21.1 deg C)		90 deg F (32.2 deg C)	
lb	kg	lb	kg	lb	kg	lb	kg
Cattle on maintenance rations							
400	181.4	18	8.2	24	10.9	40	18.1
800	362.9	29	13.2	40	18.1	64	29.0
1200	544.3	39	17.7	53	24.0	86	39.0
1600	725.7	48	21.8	65	29.5	106	48.1
Wintering weanling calves							
400	181.4	33	15.0	44	20.0		
600	272.2	45	20.4	61	27.7		
Wintering yearling cattle							
600	272.2	48	21.8	65	29.5		
800	362.9	54	24.5	72	32.7		
Wintering pregnant heifers							
800	362.9	60	27.2	81	36.7		
1000	453.6	54	24.5	72	32.7		
Wintering mature pregnant Cows							
800	362.9	65	29.5	89	40.4		
1000	453.6	54	24.5	72	32.7		
1200	544.3	54	24.5	72	32.7		
Heifers and steers							
400	181.4	35	15.9	48	21.8	79	35.8
600	272.2	48	21.8	65	29.5	106	48.1
800	362.9	56	25.4	76	34.5	125	56.7
1000	453.6	64	29.0	85	38.6	138	62.6
Fattening calves finished as short yearlings							
400	181.4	36	16.3	48	21.8	79	35.8
600	272.2	48	21.8	65	29.5	106	48.1
900	408.2	63	28.6	85	38.6	138	62.6
Fattening yearling cattle							
600	272.2	54	24.5	72	32.7	119	54.0
900	408.2	71	32.2	97	44.0	158	71.7
1100	499.0	81	36.7	109	49.4	179	81.2

*Extracted with permission from The 1969 Agricultural Engineers Yearbook. The American Society Of Agricultural Engineers, Box 229, St. Joseph, Michigan 49085.

CHAPTER 423 DAIRY

Planning Procedure

Write down each decision as it is made.

1. Determine herd size from the table below.
2. Decide on the type of each facility desired, selecting from the major alternatives listed in the outline at right.
3. Compute the sizes of all facilities using the data and suggestions throughout this book. Sketch each major building or facility. You'll need an idea of the sizes before you can plan further.
4. Identify possible sites, considering such things as overall size, access from the rest of the farm and farmstead, and possible use of existing buildings. The best site may well not include the old barn, which may have been poorly located.
The site selected will affect the layout of buildings and facilities, and the layout needed will affect the choice of the best site.
5. Sketch tentative layouts for each possible site, using the recommendations for orientation, traffic routes with all-weather access, snow and wind control, drainage, waste disposal, and the building sizes selected.
6. Select the combination of site and layout which best fits your needs and the recommendations given.
7. After all decisions are made, and before starting construction, get approval from health and marketing authorities.

Facilities needed

Housing

- Milking Herd
 - Free stall
 - open lot, cold covered, warm enclosed
 - Stanchion barn
 - stanchion, tie stall, comfort stall
- Dry Cows and Heifers
 - Free stall, loafing shed, stanchion
- Calves
 - 0 to 6 weeks of age
 - individual stalls or pens
 - 6 weeks to 10 months of age
 - pens—solid or slotted floor, loafing sheds, free stall

Milk Handling

- Stanchion Milking
- Milking Parlor
- Milk House

Feed Storage

- Roughage
- Grain

Feeding Facilities

- Stanchion Barn
- Free Stall
- Milking Parlor

Manure Handling Facilities

- Solid Waste Handling
 - Stacking, daily hauling
- Liquid Waste Handling
 - Slotted or solid floors, tanks, lagoons

Table 423-1. The make-up of a typical dairy herd.

		Milking Cows ¹	10	20	30	40	50	100
		Dry Cows	2	5	7	9	11	22
		Total Mature Cows	12	25	37	49	61	122
Weights of mature cows in milk		Heifers, 10 months to freshening	5	11	16	21	27	53
		Calves, 1½ to 10 months old ²	3	6	9	12	15	29
		Calves, Up to 1½ months old ³	2	4	6	7	9	18
		Total Animals in Herd	22	46	68	89	112	222
Breed	Weight							
Jerseys	1000 lbs							
Guernseys	1100 lbs							
Ayrshires	1200 lbs							
Brown Swiss	1400 lbs							
Holsteins	1500 lbs							

1. Milking cows = cows in milk.

2. Bull calves raised for sale will increase this figure.

3. Includes all calves—bulls and heifers.

Housing definitions

"Cold" housing—means cold in winter. It is designed to use natural air movement to keep inside temperatures within a few degrees of outside conditions.

"Warm" housing—means warm in winter. It is designed to use fans to provide air movement, at least in winter. Insulation helps retain animal heat to keep inside temperatures above about 45° in winter.

Stanchion barn—each cow is tied in a stanchion, tie stall, or comfort stall. Buildings are usually insulated, ventilated, and operated warm (45°-50° in winter). Cows may be milked in the stanchion or in a milking room.

Loose Housing—cows are free to move between resting, feeding, and watering areas. Cows rest in free stalls or loafing sheds (manure pack). Cows are usually milked in a milking room.

Open lot—loose housing with feeding and watering outdoors; resting in a shed with free stalls for the milking herd, free stalls or manure pack for dry cows and youngstock.

Enclosed—loose housing with all facilities under roof: usually free stalls, mechanical bunk feeding, and milking parlor. The building may be open front, closed but uninsulated ("cold" housing), or insulated and ventilated for "warm" operation.

Milking herd housing

Two types of housing are common for the milking herd: stanchion (or stall) barns and free stall housing. Some loose housing systems are still used but most have been converted to free stalls. Weigh the advantages and disadvantages of each, study the alternatives in each system, consider the initial and operating costs of each and, above all, develop a complete plan before construction begins.

A *free stall barn* is of most interest for the growing herd. Chores are readily mechanized, flexibility in herd size is easily accomplished, and milking parlor milking is most adaptable. Also, bedding requirements are low and liquid manure systems work well.

Problems in a free stall barn include handling manure as a solid, manure spread over solid floor

areas, moisture control in "warm" free stall systems, freezing in "cold" free stall systems, and maintaining dirt floors in stalls.

The *stanchion barn* is the most common in the upper midwest, particularly for milking herds under 50 cows. Many herds of this size have grown gradually by adding to an existing barn.

For larger herds there is more interest in building a new free stall facility for milking cows, and using the old barn for calves and heifers.

The stanchion barn permits orderly arrangement of cows in stalls and individual attention to each cow. Barn cleaning and manure hauling are daily chores. Chores are less easily mechanized so labor requirements per cow are generally higher.

Herd size should equal the number of stanchions available.

Three types of stanchions are in use: stanchions, tie stalls, and comfort stalls.

Stanchion

- Requires minimum space
- Less time required "stanchioning" as compared to other types.
- Can be lever operated.
- Cow has less freedom.
- Older cows may have difficulty in getting up and down.
- Heifers with calf should be stanchioned early enough to get used to getting up and down.

Tie Stall

- Provides more cow comfort and freedom.
- Easier for the cow to get up and down.
- Requires more space.
- Higher level of management needed to keep cows clean.
- Extra time required in tying and untying cows.

Comfort Stall

- Similar to a tie stall.
- Cow can reach full width of manger.
- Vacuum and water lines in front of the cow put her in a better position to drop manure when she raises her head.
- Pipes may interfere with tying and untying some cows.

Free Stalls

Free stalls have become popular in new construction of confinement housing with bunk feeding and central milking. Both stanchion barns and loose housing areas have been converted to free stalls.

- Provide a stall for each animal +5%.
- Do not feed or water in stalls.

In severe climates, consider warm or enclosed cold housing. In moderate climates, free stalls may be used in open-front resting sheds.

The advantages of free stalls over loafing sheds are:

- Bedding costs may be reduced up to 75% compared with a manure pack that is not carefully managed.
- Less labor is required to clean and bed stalls.
- Cows are cleaner, requiring less cow-washing time.
- Resting area requirement is less.
60-80 sq ft/cow in conventional loafing sheds.
Down to 50 sq ft/cow in free-stall housing.

But, a free stall resting area will cost more than a conventional open resting area.

Provide box stalls (120 sq ft each) or stanchions to confine cows in heat and for artificial breeding: 1 stall per 20 cows in milking herd. Include water and feeding space. Locate for convenience of veterinarian, and for ease in separating cows at milking time.

Cow Introduction

A few days may be necessary to acquaint the animals with free stall housing. During this period:

- Fill bedded area about half full to prevent cows from kicking the bedding into the alley.
- Cows may rest in the alley; if so, tie the resisting animals (2%-3% of herd, usually older cows) in the stalls for a few nights.

After the animals are acquainted with the stalls, fill the bedded area to almost full height of the curb and add bedding as required.

Some cows familiar with other systems may not adapt to free stalls.

Cleaning

Remove manure from the bedding and curb twice a day. A good time for one cleaning is in the morning right after the animals get up.

Scrape alleys at least once a day. Some operators flush the alleys with water.

A typical cleaning time is 20 minutes per day for a 50-cow herd.

Facilities for handling sloppy manure with little bedding are required. A manure loading ramp and

an end gate on the manure spreader, or a liquid manure tank, have proven satisfactory.

Ventilation

Ventilation is essential to prevent condensation. Openings under eaves, ridge vents, and openings in walls provide ventilation.

In severe climates, locate large openings in only one wall to prevent drafts. In moist or cold climates, a solid or insulated roof deck, with vapor barrier below, will reduce condensation.

Alley

Pave the alley, and make it about 10' wide to accommodate cleaning equipment. Slope it 1"/10' in direction of manure movement, but do not provide a crown.

A continuous curb, 8"-10" high, is needed along both sides of the alley. Use pressure-treated plank on edge, or 4"-6" wide concrete. Install a concrete curb if water flushing is used. Some milk markets may not approve plank.

Stall Dimensions

Consider longer stalls for longer building usefulness—cows are getting larger with improved breeding and feeding; a long stall can be made shorter, but a short stall can't be lengthened. Control dunging with neck rails. Greater cow comfort and cows not hanging over curb are additional advantages.

Stall Floor

Stall fill and floor are usually crushed limestone or dirt, plus bedding. Sand or gravel floors are not recommended, especially where liquid manure pumps are used.

Partitions

Partitions start 18"-20" above floor level so legs will not get caught. Slant alley post inward 1' to 2' or set alley post back from alley to facilitate cleaning. Posts may be 4"x4" or 4"x6" wood, pressure preservative treated or 1/2" standard pipe.

A low top rail prevents installing a neck rail to control dunging, and may also permit the cows to stand sideways with heads over the partition.

After cows are adjusted to stalls mount a training rail 18"-24" (large vs small breeds) from the front of the stall to help keep stalls clean. Adjust to minimize dunging in the stalls.

Table 423-2. Dimensions of free stalls.

Calves	
0-6 weeks	1½' x 3½'
6 weeks to 6 months	2' x 4'
6-10 months	2½' x 4½'
Heifers	
Weight, herd average	3' x 5'
1000 lb	3'-6" x 6'-10"
1200	3'-9" x 7'-0"
1400	4'-0" x 7'-2"
1600	4'-2" x 7'-4"

In pole buildings, stalls may extend to siding, permitting narrower building or wider alleys; stalls will be too short if barn is later insulated and lined.

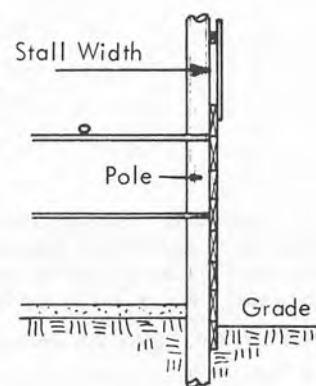


Fig 423-1. Typical free stall details.

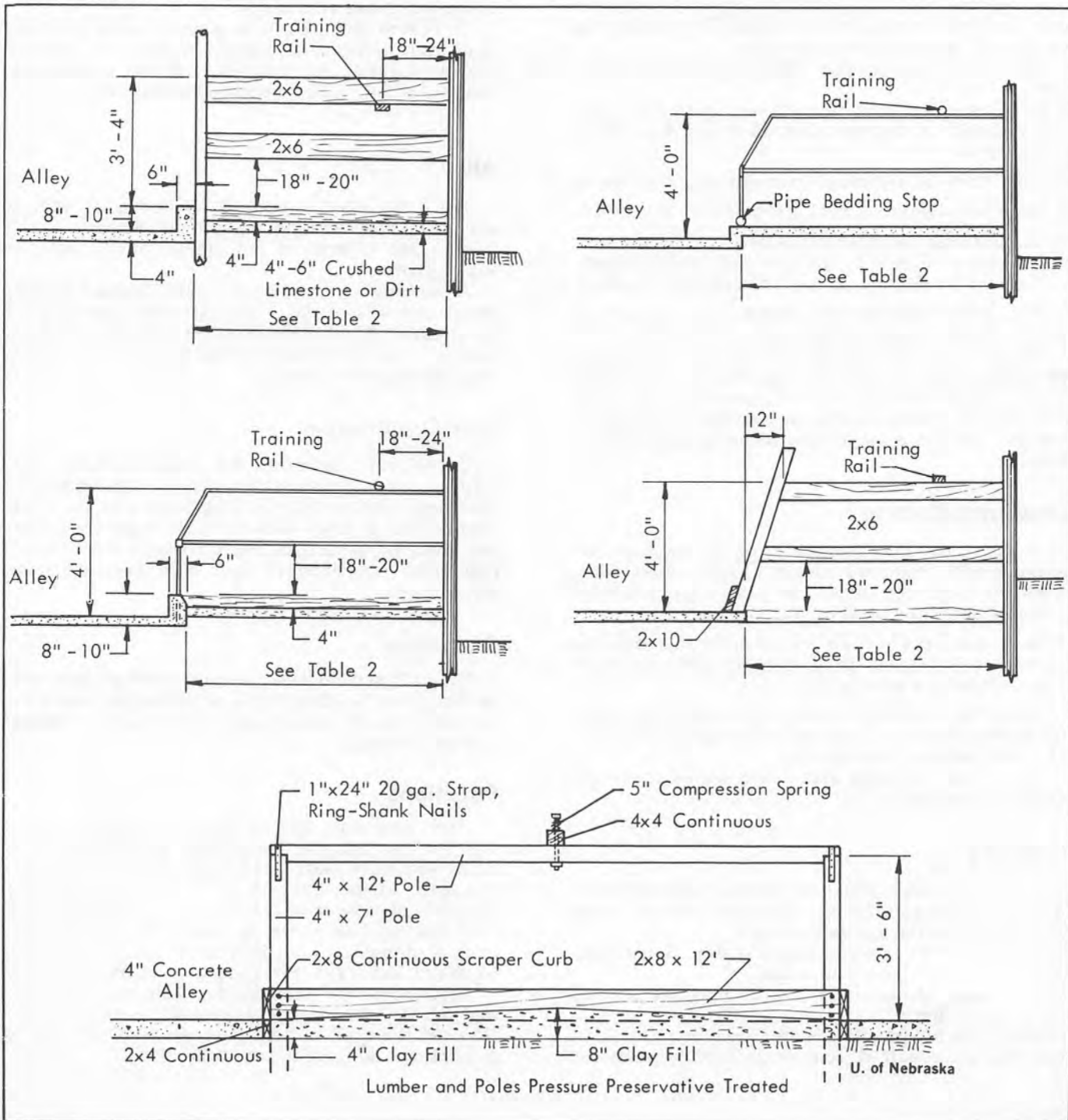
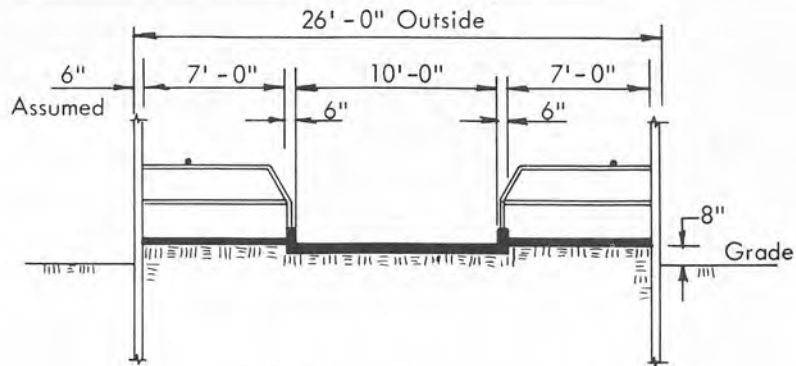
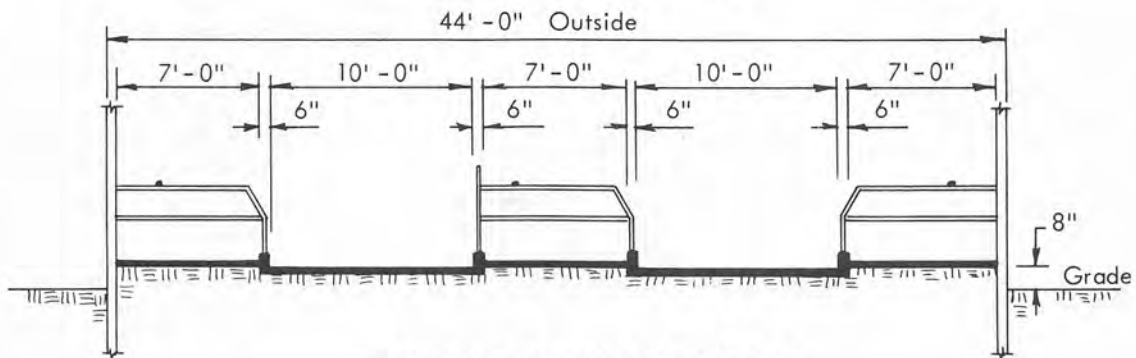
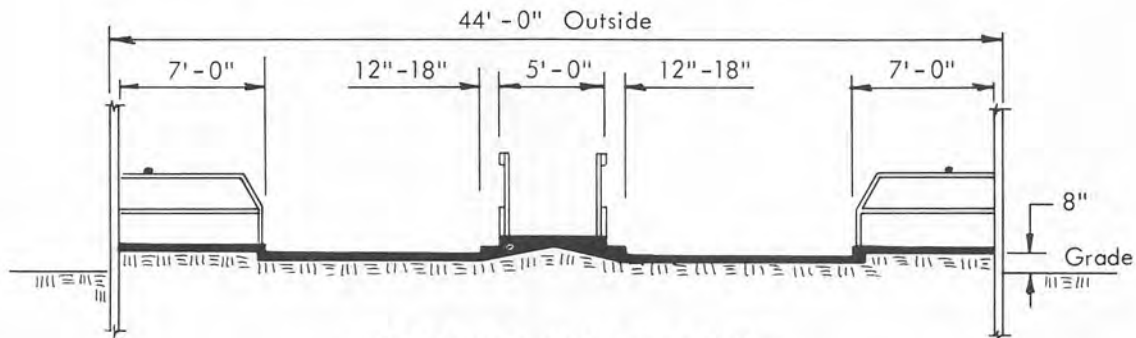
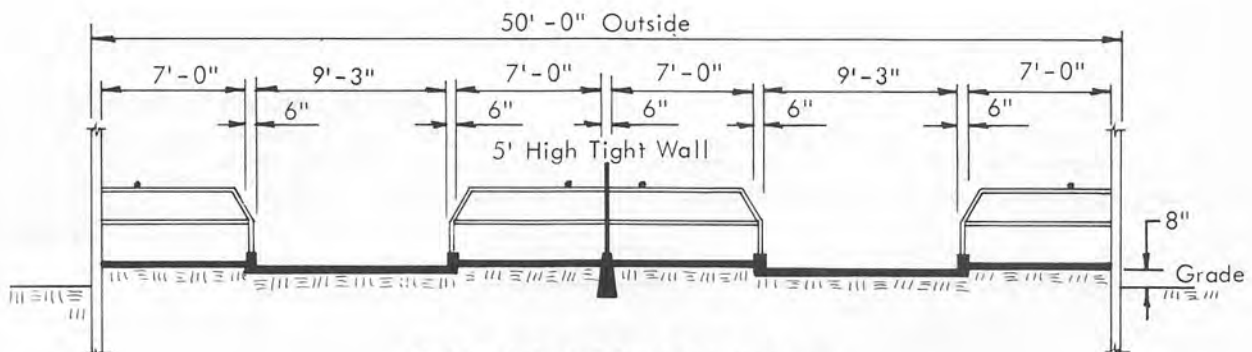


Fig 423-2. Typical free-stall barn cross sections.

Stalls are shown 7' long; walls and curbs are assumed 6" thick. Alley width may be adjusted for other stall lengths, and wall and curb thicknesses.

**1 ALLEY, 2 ROWS OF STALLS****2 ALLEYS, 3 ROWS OF STALLS****2 ALLEYS, 2 ROWS OF STALLS****2 ALLEYS, 4 ROWS OF STALLS**

Confined Free Stall Layouts

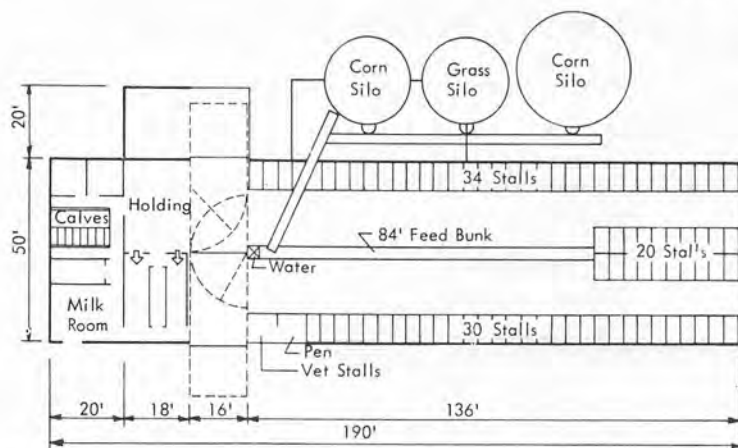


Fig 423-3. Layout for 84 milking cows.

An efficient layout for calves to 6 weeks, and for holding and milking 84 cows, is at the end of a free stall housing and feeding barn. Dotted lines indicate possible location of a liquid manure tank. Michigan State U. Plan 723-C1-83

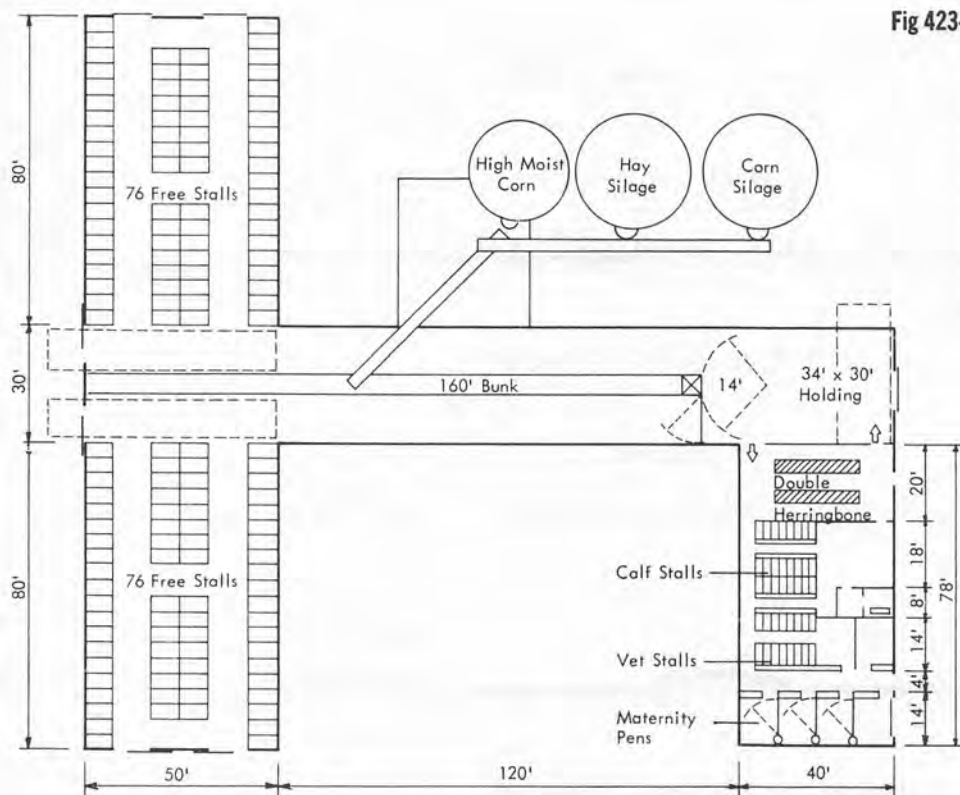


Fig 423-4. Layout with free stalls for 152 milking cows.

This layout shows free stalls for 152 milking cows. Other facilities are needed for dry cows, and young stock. The herd can be divided into two groups on the basis of production so separate rations can be fed to each group. Liquid manure tanks can be located as shown with dotted lines. A side unloading wagon may be used for feeding, permitting silage storage elsewhere on the farm. Michigan State U. Plan 723-C1-86

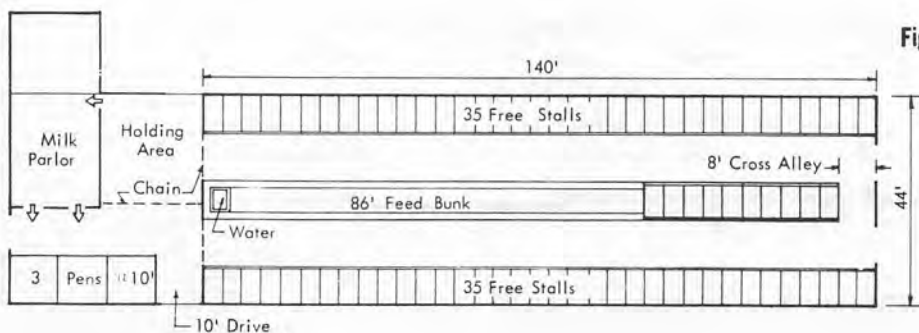
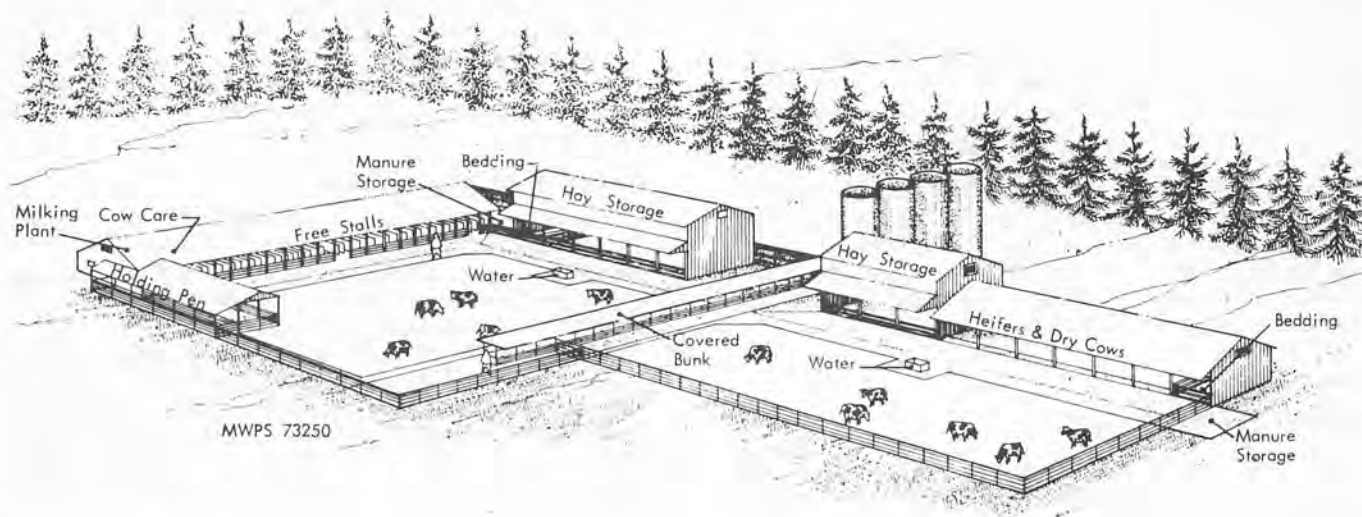


Fig 423-5. Layout with free stalls for 80 milking cows.

A simple arrangement for free stall housing for 80 cows. Other housing will be needed for calves, young stock, and dry cows. Bunk may be filled mechanically or from feed wagon.

FREE STALL OPEN LOT



Planning Procedure

1. Compute the areas needed, both for now and for future expansion.
2. Select a site.
3. Sketch tentative layouts.
4. Establish traffic routes for animals, cleaning equipment, supply trucks, etc.
5. Compare several trial layouts with the recommendations given. Any layout will require compromises.
6. Have plan approved by marketing and public health authorities.

Building Orientation

Locate structures to avoid continuous shadows in the lot, especially in freezing climates. Snow and frozen manure accumulate on the north side of buildings, bunks and silos.

Face the long, open side of buildings away from prevailing winter winds. Winter sun will provide drying on the south side, and will heat west walls and roof slopes.

Housing opening to the south will have maximum drying under the eaves, but will have minimum heating at the back wall. If it opens to the east, it will have maximum rear wall heating, and also better wind protection in areas with westerly or southwesterly winter winds.

The hay self-feeding area (paved) may extend back into the building as the winter progresses. Maximum drying will occur with the opening to the south or southwest.

Locate an uncovered holding pen where it will receive maximum sunlight and be sheltered from the wind.

The milking plant must be accessible to the milk truck, grain delivery, and next to the holding pen. Provide stanchions, or at least a catch pen and headgate, near the milking plant for veterinary or other individual cow care.

Site Selection

Arrange layout on a well-drained site. Provide a 4% ($\frac{1}{2}$ "/ft) to 6% ($\frac{3}{4}$ "/ft) slope preferably away from prevailing winter winds, usually south or east. Slopes over 10% ($1\frac{1}{4}$ "/ft) may erode in unpaved lots. A slight north or west slope can usually be graded to a south or east slope. Consider moving from present lot site to obtain desirable slope. Complete land grading for buildings and yard before starting construction.

Drainage

Use road ditches or terraces as drainageways to intercept surface water from outside the lot. Slope lots away from buildings and feeding lines.

Use paved aprons along buildings and bunks, and around waterers, to control drainage inside the lot. The following slopes are suggested:

- 1"/ft away from bunks and waterers. This slope is nearly self-cleaning.
- $\frac{1}{2}$ " to $\frac{3}{4}$ "/ft away from buildings; cross drainage in aprons.
- $\frac{1}{4}$ " to $\frac{1}{2}$ "/ft slope along drainageways.
- $\frac{1}{4}$ "/ft floor slope in buildings toward drains or open front.

Mound unpaved lot areas and drain toward pavement or outside the lot.

Lighting

For open-front buildings, some artificial lighting is desirable (100 watts per 500 sq ft).

Some codes require windows or skylights in open buildings 40' or more deep to provide natural light along the back wall. There are some disadvantages: condensation on the cold surfaces, cost, loss of dark areas for cows to get away from flies, extra heat in the summer if windows face west.

For closed buildings, provide 100 watts of artificial lighting per 500 sq ft of floor area.

Paved Yard Areas

Pavement keeps the cows out of deep mud and permits easy cleaning of heavy traffic areas. Pave around waterers, along buildings and feed bunks, the holding pen, and animal routes between these areas. Some states require a minimum paved area of 75 to 100 sq ft/cow with open lot housing. Traffic routes for cows and vehicles should be at least 12' wide. The road between two parallel fenceline bunks may be up to 30' wide and sloped to the center to provide drainage and space for plowed snow. A turn-around area is required.

Unpaved Yard Areas

Unpaved yard areas should be well graded and drained. They provide exercise space during part of the year and can be used for snow and manure storage during winter months. Cows may need to be fenced away from muddy unpaved areas.

Summer exercise lots are common for herds not put on pasture. Alternate herd between at least two lots with a total area of about 1 acre per 24 cows.

Bedded Resting Area (manure pack)

A conventional loose housing resting area with a manure pack is adequate for youngstock or dry cows but is not recommended for the milking herd. Space Required:

- 40 sq ft/heifer.
- 50 sq ft/cow in southern zones.
- 60 sq ft/cow in northern zones.
- 75 sq ft/milking cow required in some areas.

Planning and Construction

Do not feed or water in the resting area.

Minimize cow traffic across the resting area by having only outdoor access between the resting area and other areas. Provide enough doorways to the yard to prevent concentrated traffic lanes.

Because the open side is relatively unprotected, the shed should be at least 30' deep in moderate climates and 40' deep in severe climates, in addition to any bedding storage.

Foundations, walls, and ceiling or roof height must be designed for a 3'-4' manure pack. A minimum door opening height of 10' is recommended.

Floors can be well-drained earth about 12" above outside grade and sloped toward the open side, or paved for easy cleaning if used in the summer.

A paved apron should extend 4' into the building and preferably 16'-20' outside the eaves. Provide eave troughs.

Manure Pack Management

Start a manure pack before freezing weather to permit fermentation to start. Place 12"-18" of bedding in the resting area; shavings or corn cobs make a good base. The heat of decomposition will maintain a warm pack.

Clean the resting area before the start of the fly season (air temperatures at 65°F). Keep it dry, and clean at least weekly to interrupt the fly cycle until killing frosts in the fall. A pack is not recommended during the fly season. If the resting area is used in the summer, a concrete floor is recommended.

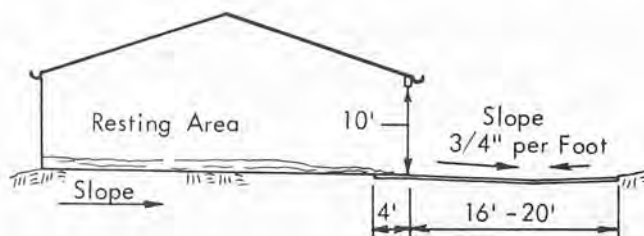


Fig 423-6. Manure pack in cold barn.

Feed Center

Locate the feed center convenient to the feeding area, and away from cattle traffic. Avoid blocking summer breezes. Consider snow drifting. Provide all-weather access. Storage and distribution of ground feed is usually at the milking plant.

Shade

Allow 20-25 sq ft/head—more for hot climates. North/south orientation permits sun drying under a long narrow shade. Permanent shades should be on a graded rise for drainage and have 10' minimum clearance. Where covered bunks provide shade, resting cattle may interfere with feeding.

Major dimensions for housing cows in stanchions are given on the next few pages. Check with your barn equipment supplier before starting construction, so that dimensions match equipment to be installed. And, as with other dairy installations, get approval from health and marketing authorities.

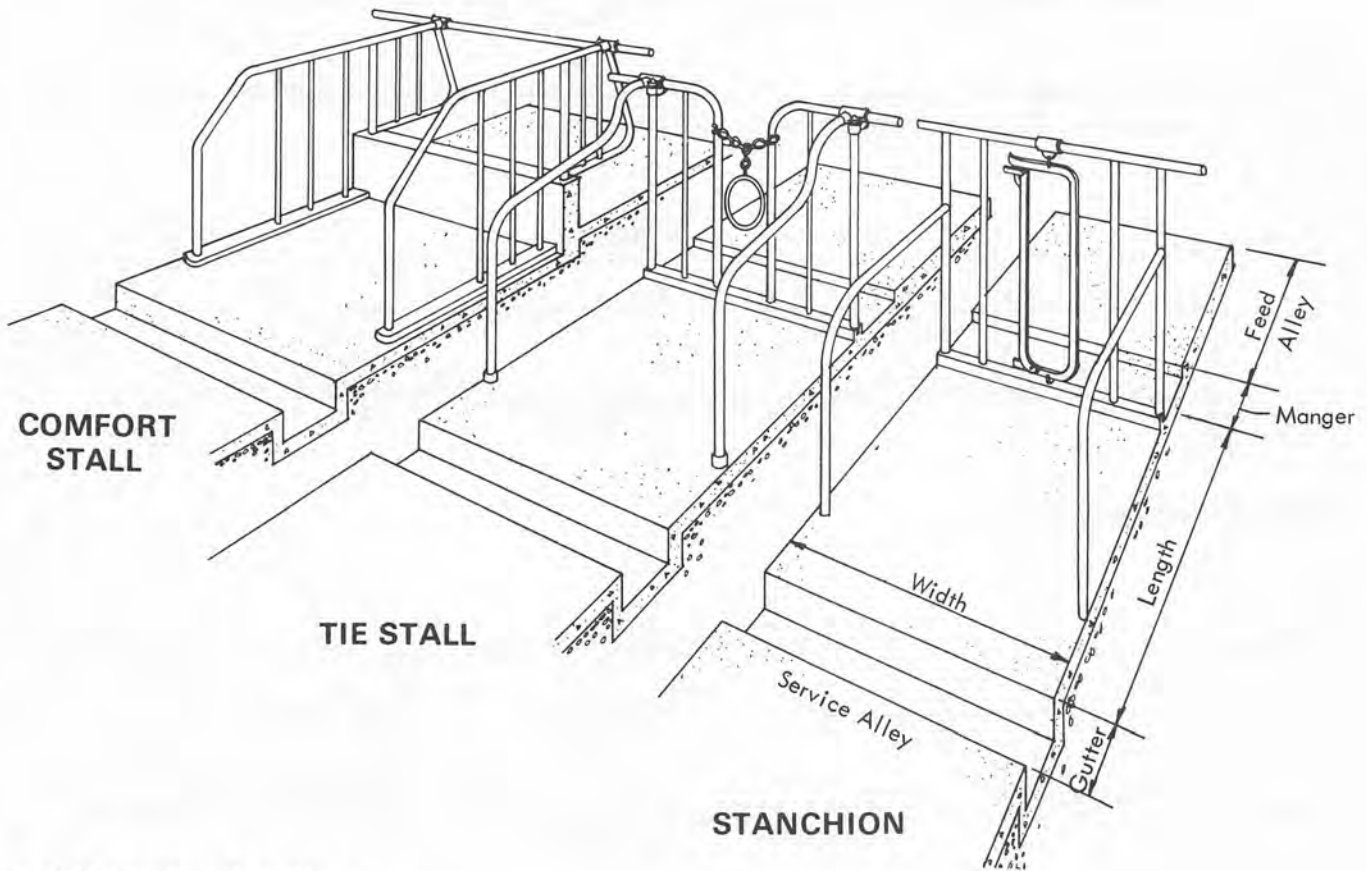


Fig 423-7. Three types of stanchions.

Table 423-3. Sizes of cow stanchions (using electric cow trainers).

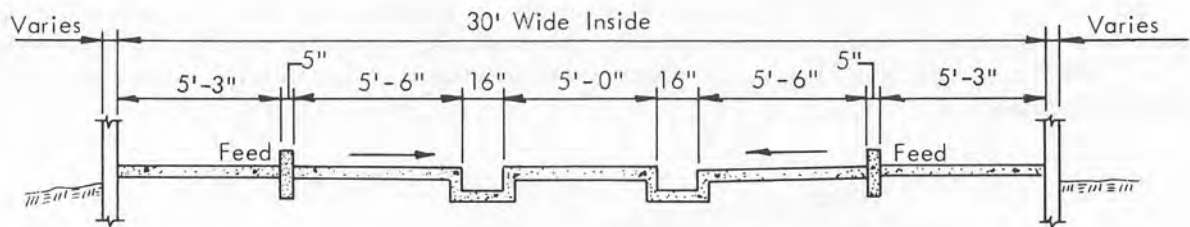
Weight of Cow	Stanchions		Comfort Stalls		Tie Stalls	
	Width	Length	Width	Length	Width	Length
1200 lbs	4'-0"	5'-4"	4'-3"	5'-7"	4'-6"	5'-10"
1400 lbs	4'-3"	5'-8"	4'-6"	5'-11"	4'-9"	6'-2"
1600 lbs and over	4'-6"	6'-0"	4'-9"	6'-3"	5'-0"	6'-6"

Table 423-4. Stanchion barn dimensions.

	Dimensions	
	Minimum	Recommended
Alleys: Feed alleys for sweep in mangers ¹	3'-6"	4'-4'-6"
Cross alleys (up to 6' wide if cow exit) ¹	3'-6"	4'-6"
Service alleys for barn cleaner	5'-0"	6'-0"
Service alleys for manure spreader	7'-6"	8'-0"
Mangers: Width—Cows under 1200 lbs	20"	22"-27"
Cows weighing 1200 lbs and over	22"	24"-27"
Gutters: Width ²	16"	16"
Depth—stall side ³	10"	11"-16"
Depth—alley side	8"	11"-14"

1. A five-foot wide cross alley is desirable for large feed carts.
2. Or as required for barn cleaner.
3. Gutter details vary with operator preference. With cow platform and service alley at the same level it is easier to move across the gutter. An 11" depth provides adequate capacity for daily cleaning. Many operators prefer having the cows at a higher level for better showing; effective depth of gutter is depth on service alley side.

Cross-Sections



Minimum recommended dimensions for a 1300 lb cow. Barns 30' or less wide are encountered in remodeling but are definitely not recommended for new construction.

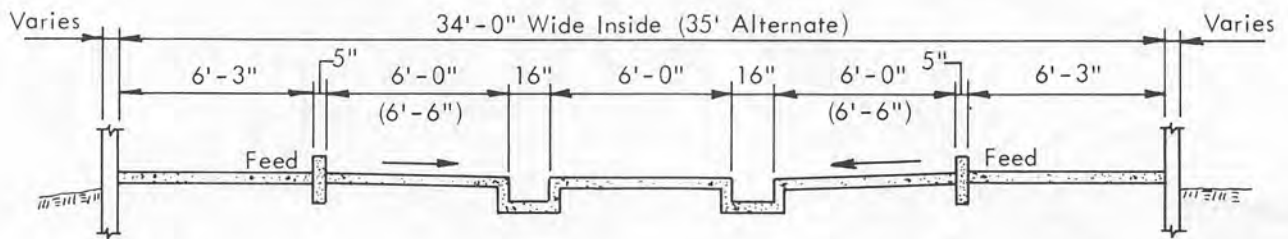


Fig 423-8. Flat feed alley—cows face in.

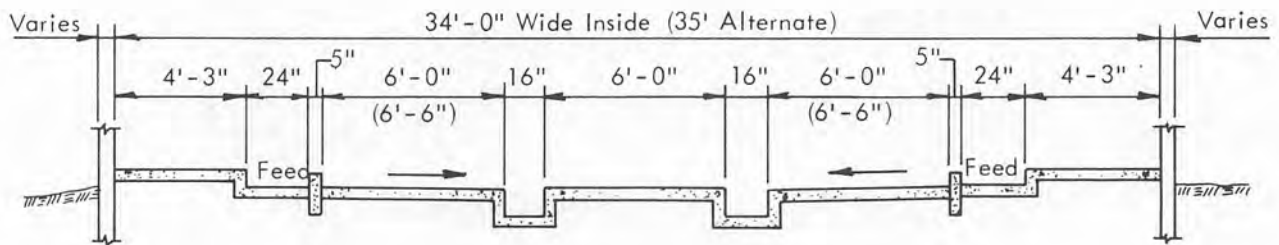


Fig 423-9. Step manger—cows face out.

New barns 36' wide outside may vary from 34'-35' wide inside. Vary cow bed length as shown in parentheses. Flat alley and step manger are shown as options.

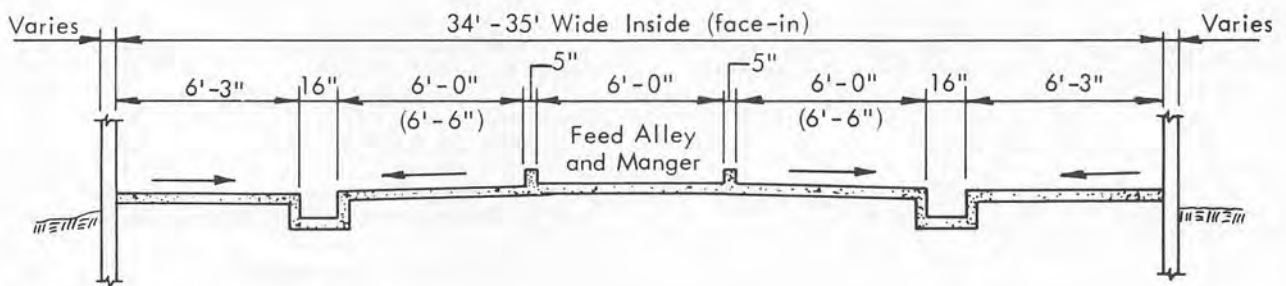


Fig 423-10. Flat manger—cows face in.

A face-in barn is more convenient for feeding, especially with mechanical distribution system. Moving cows in and out is more difficult as is arranging a convenient pen section at the end of the barn. If the barn is less than 34' wide, reduce width of cow beds—milk markets may require 6' between gutter and wall to reduce manure splatter.

Typical Layouts

Fig 423-11. Layout designed for 40 milk cows.

The layout is designed for 40 milk cows, 12 calves $1\frac{1}{2}$ to 10 months old, and 5 calves under $1\frac{1}{2}$ months old. The 1-story barn is suitable for baled or chopped hay handled in large carts. U. of Wisconsin Special Bulletin #4, 1963.

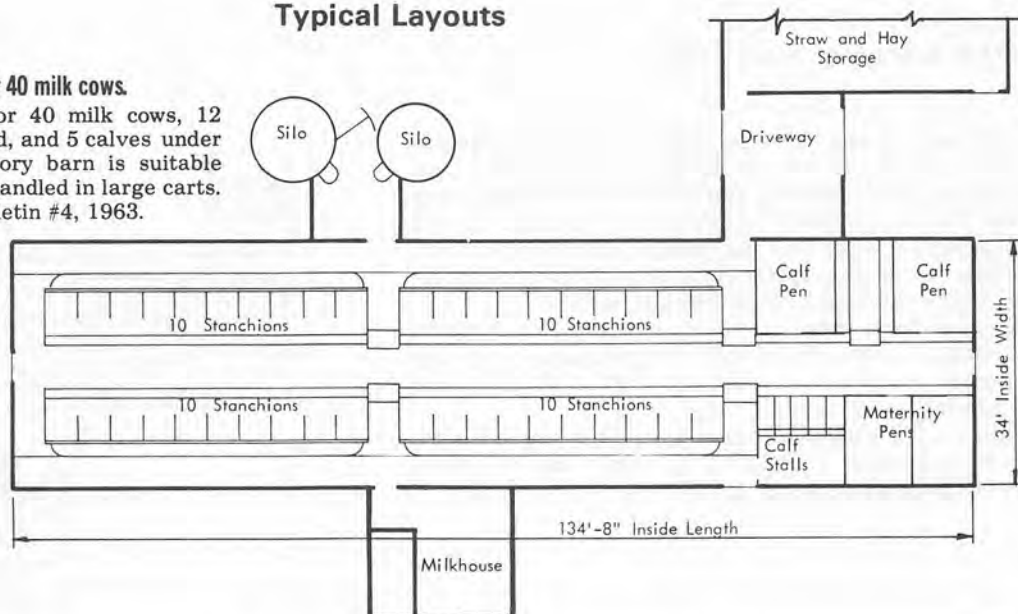
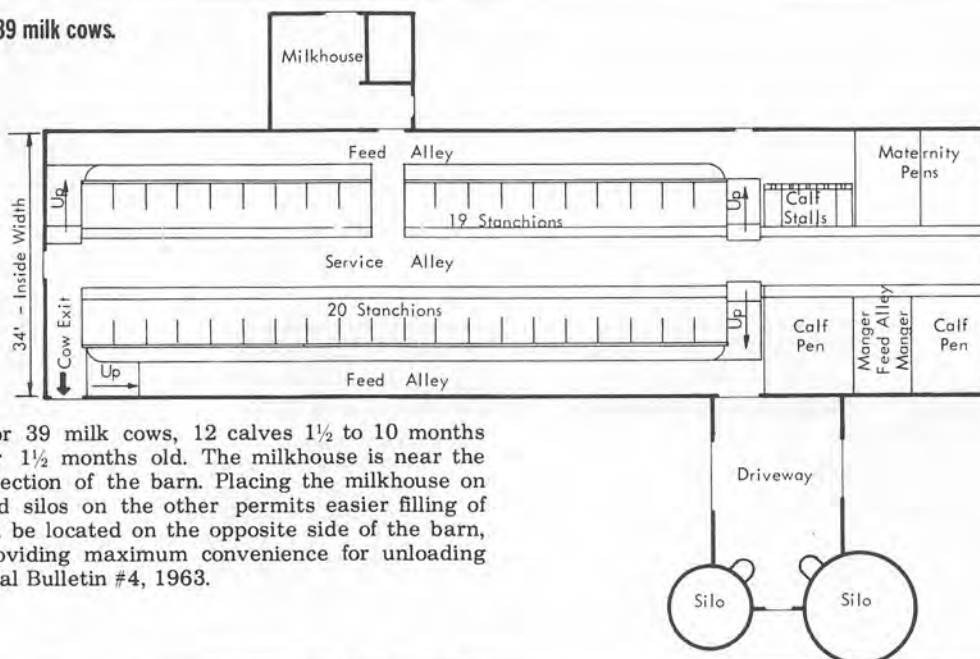
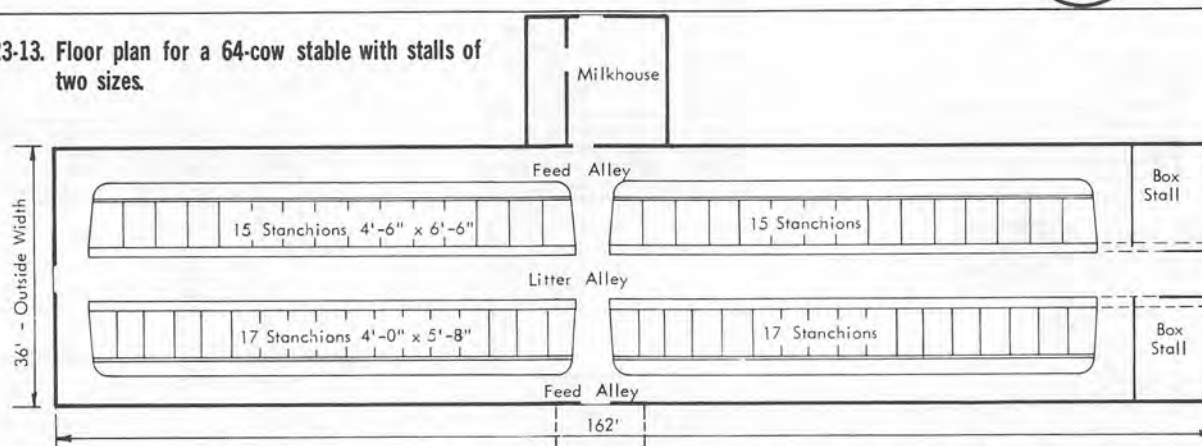


Fig 423-12. Barn designed for 39 milk cows.



This barn is designed for 39 milk cows, 12 calves $1\frac{1}{2}$ to 10 months old, and 5 calves under $1\frac{1}{2}$ months old. The milkhouse is near the center of the milk cow section of the barn. Placing the milkhouse on one side of the barn and silos on the other permits easier filling of the mow. The silos could be located on the opposite side of the barn, but with a drive-thru providing maximum convenience for unloading feed. U. of Wisconsin Special Bulletin #4, 1963.

Fig 423-13. Floor plan for a 64-cow stable with stalls of two sizes.



Floor plan for a 64-cow stable with stalls of two sizes. This arrangement is suitable for the typical herd of large breeds. Animals can be moved from small to large stanchions

as they mature. Box stalls are for sick cows or maternity pens. Provide separate facilities for youngstock and calves. U. of Minnesota Bulletin M-13, 1968

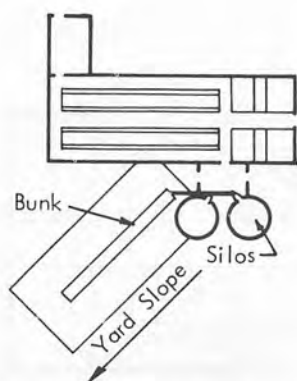
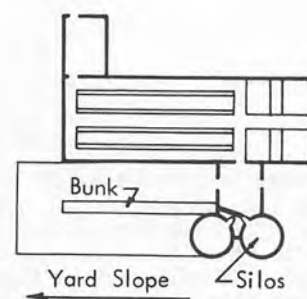
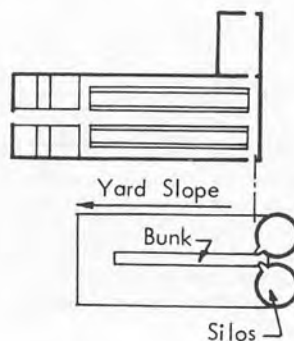
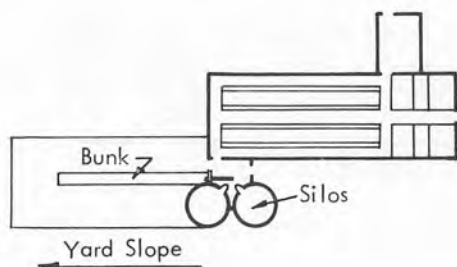
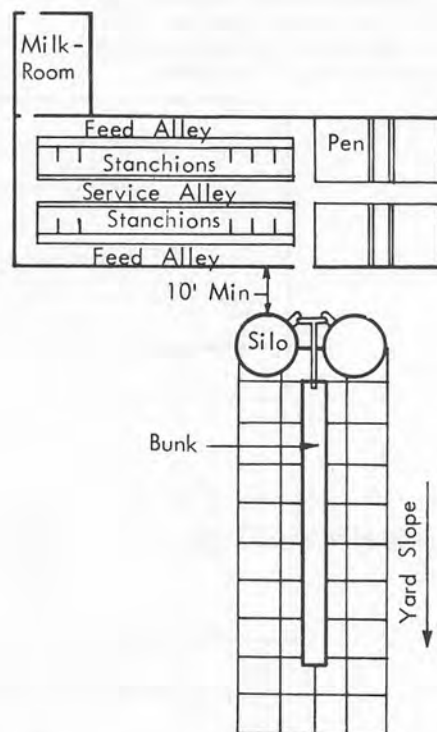
Fig 423-14. Outside silage feeding layouts.

Outside silage feeding offers relatively simple mechanization of one feeding chore. Milking and dry cows, and heifers, can all use the same bunk if the lot is divided. Consider this system if you are going toward a high-silage, low-hay ration.

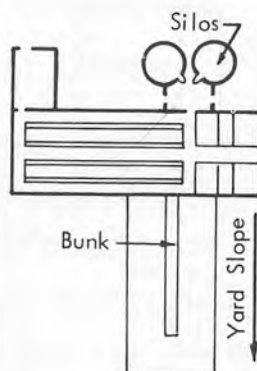
Plan for future barn expansion, convenient filling of silos, and additional bunk length.

Locate long axis of bunk in direction of slope and north-south if possible, especially in severe climates. Put bunk south of the silos to avoid accumulation of ice and frozen manure.

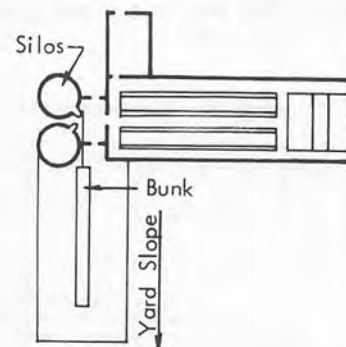
Leave 15' minimum clearance between the side of the bunk and a fence or building and 10' minimum between barn and silo.



Bunk placed at angle to permit easier silo filling



Conveyor can also drop feed at feed alleys



Locate silos on end of barn only if any future expansion can be done from the opposite end of barn

Milkhouses

Location

Locate the milkhouse on the clean side of the barn on a well-drained site. Provide access for the milk truck. Consider putting the milkhouse near the center of the length of a long barn.

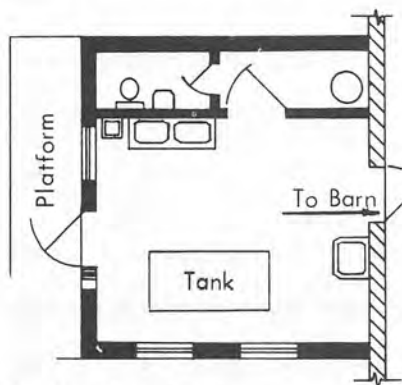


Fig 423-15. Typical milkhouse layout.

Ventilation

A milkhouse may be ventilated with an intake fan, or with an exhaust fan if intakes are provided that prevent drawing air into the milkhouse from the toilet room or the barn.

Vestibule

Most codes no longer require a vestibule. Where a vestibule is required, its size, lighting, and ventilation are usually also specified. Common requirements are: 5'-6" minimum length, one 100-watt light or equivalent, and a gravity ventilation vent in the ceiling if the vestibule is enclosed.

Milking Room

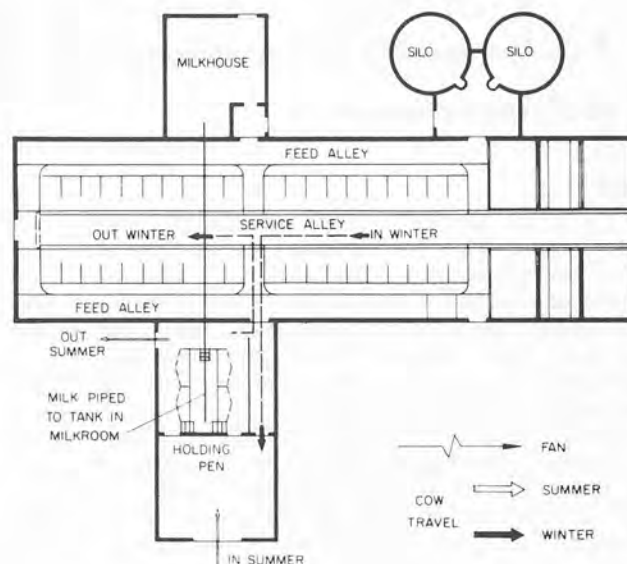
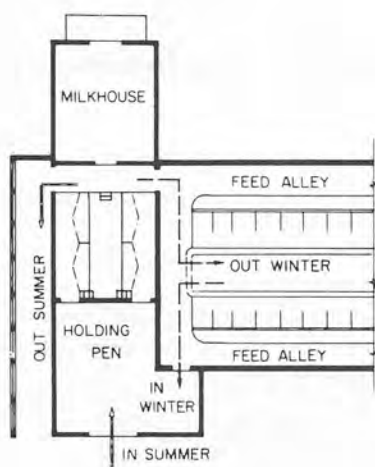


Fig 423-16. Adding a milking room to existing stanchion barn.

The arrangement will depend on present milkhouse location and access to outside yards. The milking room makes milking easier, more efficient, and perhaps more sanitary.

Milking Plant

Before starting construction, installing new equipment, or undertaking remodeling:

Contact your milk receiving station representative. He will tell you which marketing and public health standards you will have to meet. Check dimensions specified by your milk code.

Many dimensions will depend upon the specific equipment selected. The type of stall, size of cows to be milked, and variations between manufacturers all affect the size of the milking room. The size and type of milk tank, compressor location, and the kind of washing and milk handling equipment will affect the size of the milkroom.

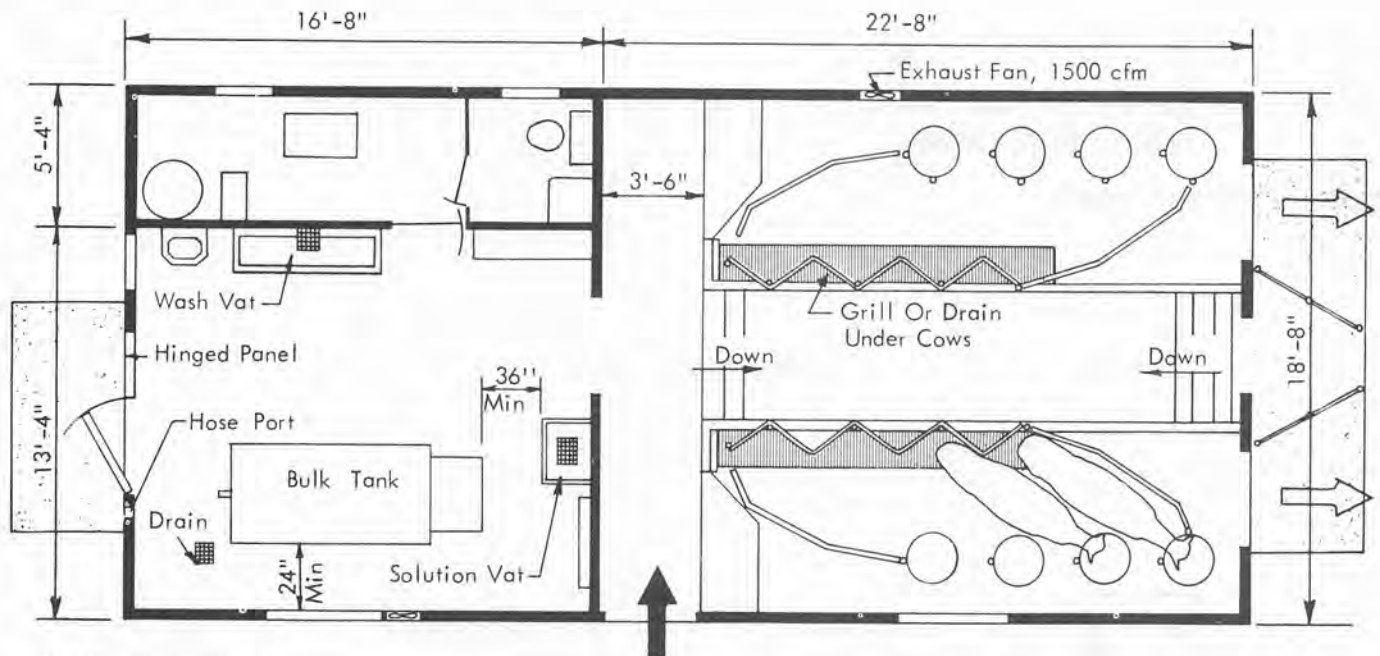


Fig 423-17. Typical milking plant layout.

Heat

Heat the milking room, milkroom, toilet, and utility room to prevent freezing in the coldest weather. Provide supplemental heat, if necessary, to maintain a 50° temperature during milking and milkroom operations. Heat from the cooler compressor, water heater, and separate heaters or furnaces can be used. Equipment heat should be exhausted in warm weather.

Heat supplied by cooling milk can be utilized to heat the milking parlor and/or milkhouse. Cooling 100 pounds of milk from 98° to 40°F supplies about 4,800 Btu of heat—about the same as a 2KW electric heater running for 1 hour. A system to utilize this heat can be built into most facilities at very little extra cost. Put the compressor, vacuum pump, water heater and furnace in one utility room. Connect the furnace blower to come on when the compressor starts. Connect the furnace to a thermostat in the milking parlor (or milkroom) so when milk heat is insufficient the furnace will come on. An insulated door to the outside can be

opened in summer so the compressor heat will be blown outside.

Ventilation

Ventilate the milkroom with a 1000 cfm intake fan to assure that air is not drawn from the milking room. Locate the fan so air is drawn in from the cleanest and most dust-free side of the building.

Air outlets can be in the utility room, toilet room, and the wall opposite the fan.

Ventilate the milking room with an exhaust fan, with inlets in the wall on the opposite side of the building, or from the attic.

Air outlets and inlets should be screened and have a total area of one square foot per 700 cfm fan capacity. Size fans in both the milkroom and milking room to move 6 air changes (6 times room volume) per hour in winter.

For summer ventilation, use fans of 12 or more air changes per hour capacity, or screened windows, or both. Attics should be vented with screened louvers and/or eave vents.

Interior Walls

Interior walls should be a light color, washable, and kept clean. The lower 4' should be impervious to water. A pipe railing 36" above the floor and 4" from walls will help protect painted surfaces where cows pass in the milking room.

Table 423-5. Durability of interior lining in milking plants.

Wall Material	Ease of Cleaning	Resistance To			
		Abrasion	Stains	Acid	Impact
Ceramic Wall Tile	E	E	E	E	F
Sheet Alum. on Plywood	G	F	F	F	G
Cement Asbestos Board	F	E	G	E	F
Structural or Salt-Grazed Tile	E	E	E	E	G-E
Cement Finish	E	G	E	G	F
Glazed Concrete Block	E	G	E	G	F
Paint	G	P	G	F	F-G
Oil or Latex Epoxy	E	E	E	E	E

E=Very Good to Excellent

G=Good

F=Fair

P=Poor

Exterior Walls—Insulation

Insulation reduces condensation on inside room surfaces, and conserves heat. A vapor barrier is required on the inside (warm side) of walls and ceilings. Polyethylene in frame construction, vapor-proof paints on masonry, etc., prevent moisture from penetrating insulation and reducing its effectiveness.

Table 423-6. Insulation required with various wall materials.

CONSTRUCTION	COLD	MODERATE	MILD
Sidewalls (Vapor Barrier Required)			
Wood or steel frame	2"-4" insulation	1"-2" insulation	1/2" insulation
Cavity wall, 4" tile, or cinder or light-weight block	4" cavity filled with insulation	2" cavity filled with insulation	----
8" cinder or light-weight concrete block, cores filled	2" insulation	1" insulation	----
8" concrete block, cores filled	3" insulation	2" insulation	----
6" concrete tilt-up sandwich wall	2"	1 1/2" foamed plastic insulation	1"
Ceiling (Vapor Barrier Required)			
Fill or batt insulation	4"-5"	2"-4"	0-2"

Floors

Slope concrete floors and gutters 1/4"/ft to all drains. For a non-skid surface, work carborundum or aluminum oxide aggregate (1/4 to 1/2 lb/sq ft) into the surface of the floor before final trowelling. In the operator's area, provide a 96 sq in. sediment type water seal drain with a 4" outlet.

Floor and wall, or floor and curb, junctions should be rounded to facilitate cleaning.

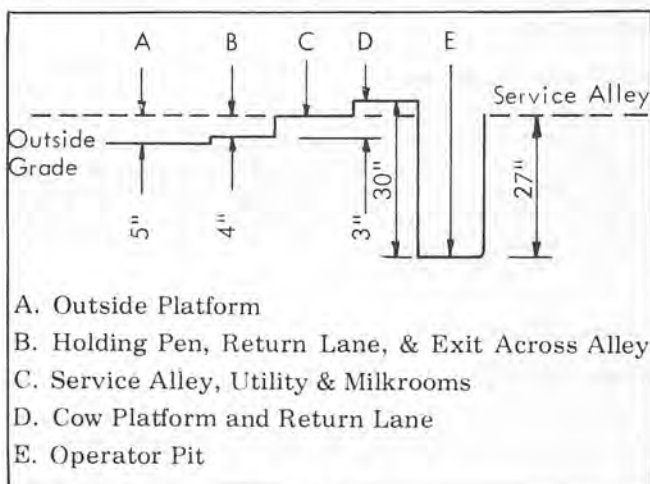


Fig 423-18. Floor levels for milking plant.

Water Supply

An adequate pressure water supply is required and should comply with local codes. Provide warm water for washing and sanitizing udders, and water under pressure for floor washing.

Mixing valves are recommended for hot and cold water and for adding bactericide for washing udders and sanitizing teat-cups.

Water Heater Capacity (Minimum)

Bulk tank up to 400 gal—50 gal heater; bulk tank over 500 gal—80 gal heater. An 80-gallon water heater is minimum with an automatic pipe-line washer.

Compressor

If the compressor is remote from the bulk tank, provision to control the condenser cooling air for use in winter heating can be provided as shown below. This arrangement permits compressor heat to be blown out of the building in summer.

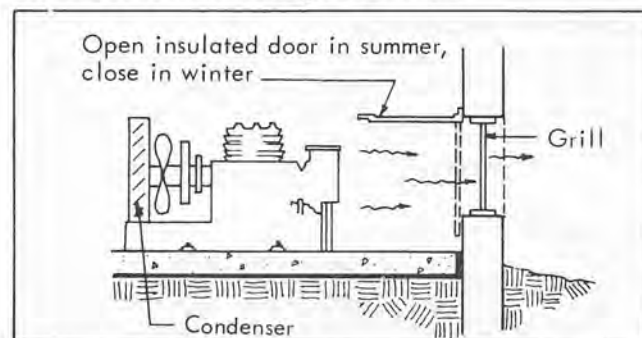


Fig 423-19. Installation of a compressor.

Utility Room

A separate room is desirable in the milking plant for the vacuum pump, electric entrance box, heating plant, hot water heater, bulk tank compressor, and fuel storage. A tight-fitting door between utility room and milkroom is required if coal is used as a fuel. A flame-type water heater and air space heater require a chimney. Good lighting, ventilation, and a floor drain are required. Heat generated from this equipment can be used to heat the milking plant.

Toilet and Washroom

A washroom with hand washing facilities, toilet, and optional shower is recommended in the farm milking plant. This room cannot open directly into the milkroom, but may open into a vented vestibule, the milking room, or the utility room. Provide heat in severe climates.

Milking Room

Floors and Drains

Allow 4" to 6" toe space next to the milking stalls, or 8" if a bull nose gutter is used next to the milking stall.

A curb may be placed along the edge of the stall floor next to the operator's area. Bucket or swinging milkers require a cut-out curb in front of the udder. The curb may be less than an inch high if the edge of the curb extends 3" outside the stall pipes toward the operator.

Lighting

A single row of 40-watt fluorescent lights over each cow platform, and a single row down the center of the operator's alley, will provide approximately the 20 footcandles of general lighting recommended by the American Society of Agricultural Engineers.

Incandescent floods or spots can provide local lighting at the cows' udders.

Doors

Provide a solid, tight-fitting, self-closing door between the milkroom and the milking room. A door which swings both ways is convenient, if permitted. A single-action door should open outward from the milkroom. A vestibule is not usually required where the cows are not housed in the area where they are milked. Cow entrance doors are opened by the operator. Exit doors are often cow operated.

Concentrate Feed Storage

If cows are fed in the milking room, feed storage should be dust tight, dry, rodent proof, and arranged for convenient filling. Dust in the milking room or milkroom is objectionable. Arrange for hand or metered feeding at each milking stall.

Milkroom

Provide enough space for all equipment, and adequate clearances around the bulk tank. The bulk tank should hold 3 milkings at peak production

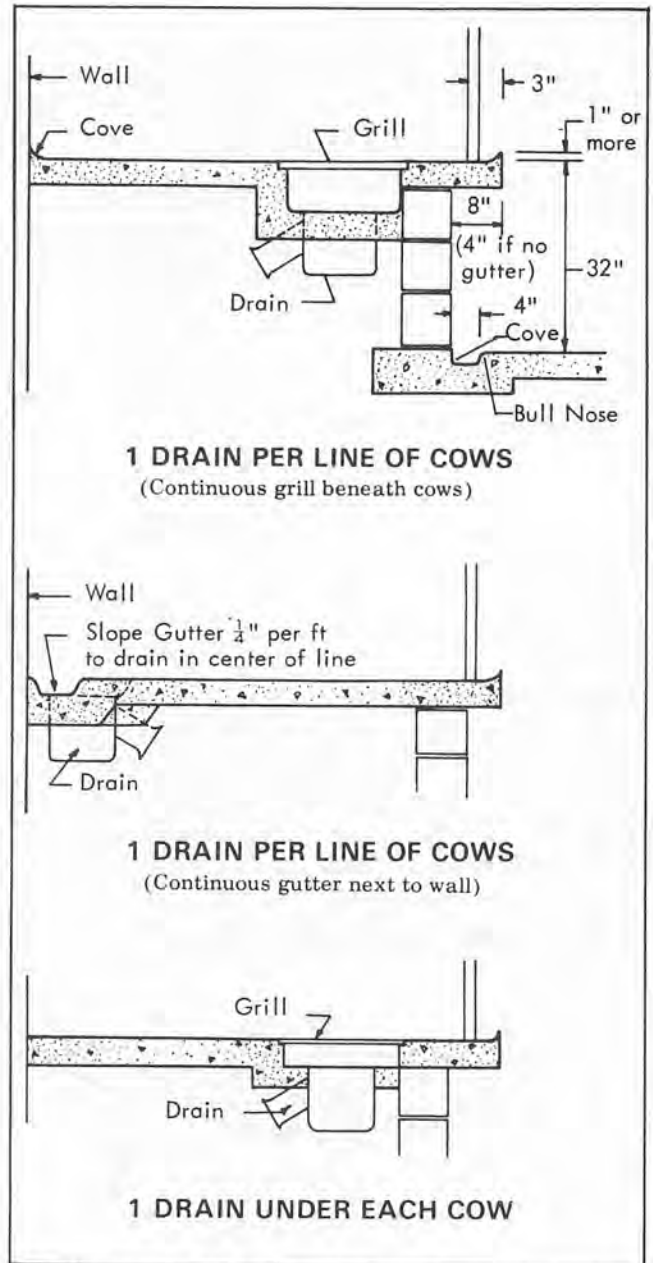


Fig 423-20. Optional drain lines used in milking room.

with every day pickup. Increase to 5 milkings capacity with every-other-day pickup.

Minimum floor area for milkroom is about 200 sq ft. Most important are space to work, clearance around equipment, and room for equipment.

Working Space Around a Bulk Tank

Provide at least the following clear distances between the bulk tank and equipment or a wall: 24" from the rear end and side of the tank. 36" from the outlet valve and front (working) side.

Some codes permit smaller distances for remodeling.

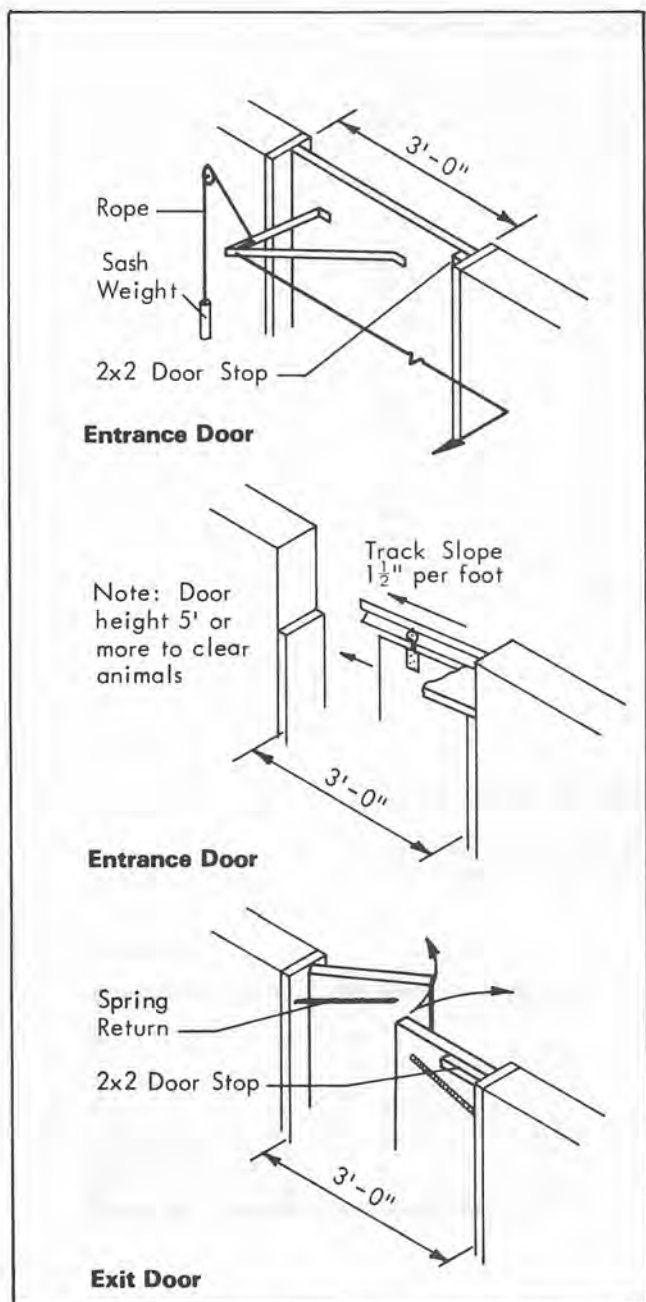


Fig 423-21. Entrance and exit doors for cows from milking room.

Loading Platform

Provide a concrete loading platform, or slab on grade, about 4'x8' and convenient to the service drive. Provide a self-closing hose port far enough off the floor to permit starting the hose through the port without touching the floor.

Doors

Provide an inside door and a combination screen and storm door for the milkhouse and milking parlor. Some codes will not allow a direct door from the milkhouse to a toilet. In this case the toilet door should open into an office or utility room.

If the door opens to an unheated vestibule pipes may freeze.

Many bulk milk tanks are wider than normal doors. Put in a large double door or an insulated removable panel beside a regular door.

Floors and Drains

Provide a drain under the wash vats and a drain 24" from the bulk tank outlet valve. Avoid drains in traffic routes.

Floors under bulk tanks should be concrete reinforced slabs independent of the rest of the floors. Slope slab 1"/ft from under tank to both sides. Milkhouse and parlor may have to be elevated to provide adequate fall to waste disposal system.

Lighting and Outlets

Rows of single 40-watt fluorescent lights spaced 5' apart will provide approximately the 20 foot-candles of general lighting recommended by the American Society of Agricultural Engineers. In addition provide swivel electric light outlets to the side of the tank openings and not directly over the tank to light the inside of the bulk tank. Provide lights over the wash vats and loading platform.

Provide electrical outlets for water and space heaters, milk cooler, ventilation fans, tank unloading pump, cleaning equipment, and for general use at counters. Provide grounding conductors to all electrical equipment.

Place entrance box in the utility room. Consult local electrical codes.

Holding Pen

This area should have 12 to 15 sq ft paved for each cow milked. A covered or partially covered area protects the animals from rain and snow, helps prevent slipping, and allows time for water to drain off cows. But, an open area is exposed to sun drying and better air circulation.

Holding pens are cleaned daily. Expect half a load of manure per week per 30 cows.

Slope the holding pen floor away from the milking room entrance. If steps are used, use a 6"-8" rise with a 24" run for small breeds or 30" run for large breeds. Ramps should have a slope of less than 2"/ft. Steps are preferred to a ramp at the entrance for better cow footing. A ramp may be preferred at the exit to avoid damage to dew claws if it can be kept dry to avoid slipping.

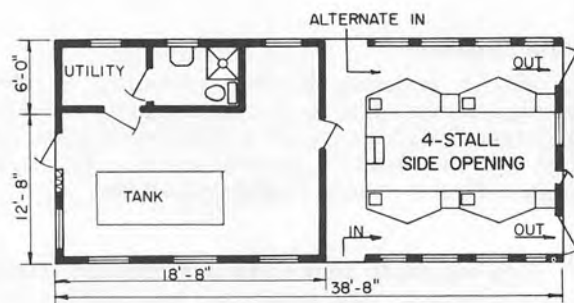
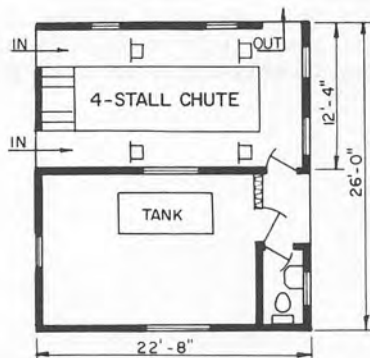
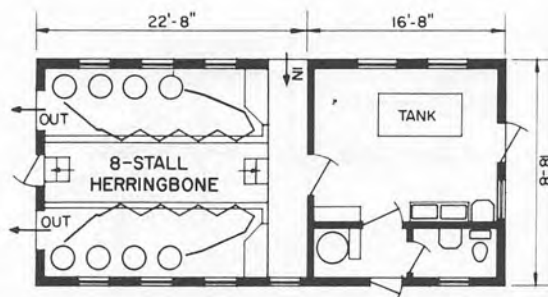
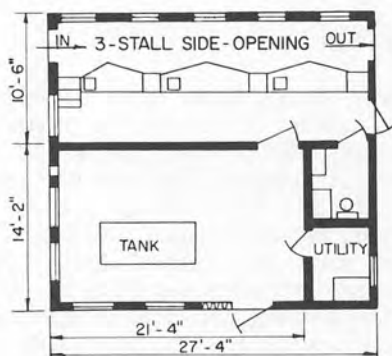
Table 423-7. Cows milked per hour with a C.L.P. pipeline milker.

Type of Milking Room and Stalls	No. of Operators	No. of Milking Units	Average No. of Cows Milked/Hour
Side-Opening Gate Stalls			
3 stalls, one side	1	3	25-30
4 stalls, one side	1	4*	25-30
2 stalls, each side	1	4*	30-35
3 stalls, each side	2	6	45-55
4 stalls, each side	2	8*	55-65
Chute or Lane Stalls			
2 stalls, each side	1	2	25-30
3 stalls, each side	1	3	30-35
Herringbone Stalls			
4 stalls, one side	1	3	28-34
4 stalls, each side	1	4	35-45
8 stalls, each side	2	8	70-80

* Only 3 units per man will operate at any one time.

Fig 423-22. Typical milking plant layouts with approximate space requirements.

Determine equipment to be installed before building or remodeling. Detailed dimensions must follow manufacturer's specifications.



Calf Housing

With calves on whole milk, and especially in cold climates, it is convenient to have maternity and calf pens near the milking plant.

With calves on milk replacer, the pens can be away from the milking herd. But, stanchions, or at least a catch pen and headgate, must be handy to the milking plant for diverting cows for veterinary or other individual care.

Warm Barn

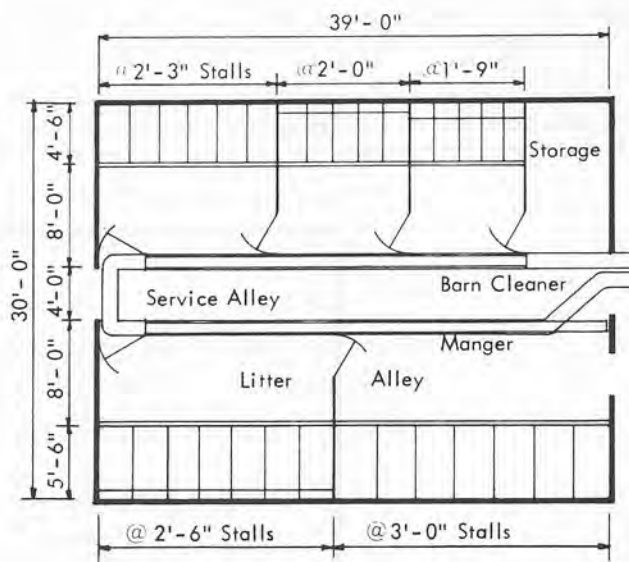
A warm barn is usually preferred for more than 10-15 calves. Maintain temperatures between 40° and 50°F. Walls should have insulating value, R, of 10 to 12. Ceilings should have insulating value, R, of 18 to 20.

Calf area should be partitioned off from milking herd so adequate conditions can be maintained for the small animals. In a warm barn calves can be tied in individual stalls to reduce floor area per animal. Automatic waterers can be provided.

Provide ventilation for winter of 1/10 cfm/lb of calf.

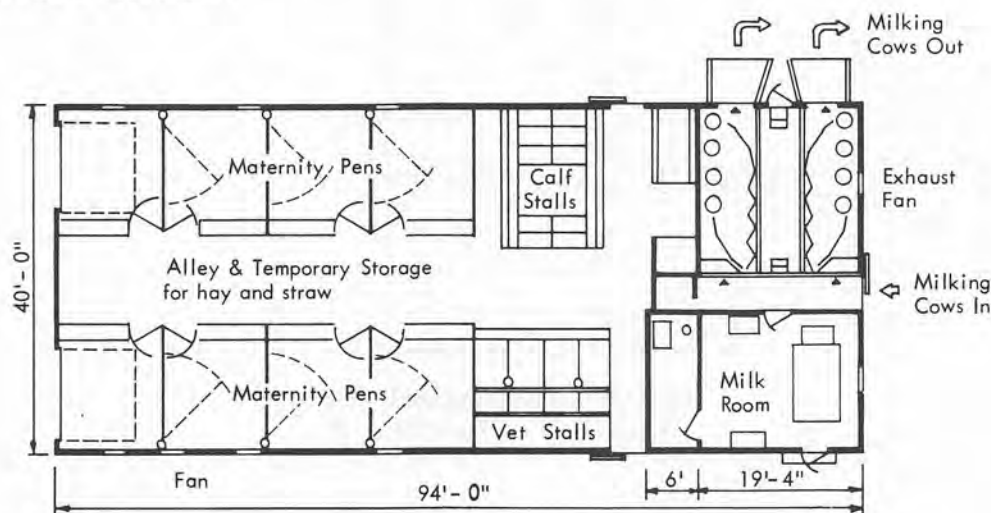
Provide heat at a rate of 10 Btu/sq ft of glass, plus 5 Btu/sq ft of wall, plus 4 Btu/lb of calf.

For electric heaters 1 kw = 3413 Btu/hr.



U. of Wisconsin

Fig 423-23. Warm calf barn.



Michigan State U Plan # 723-C1-85

Fig 423-24. Pen arrangement with milking plant.

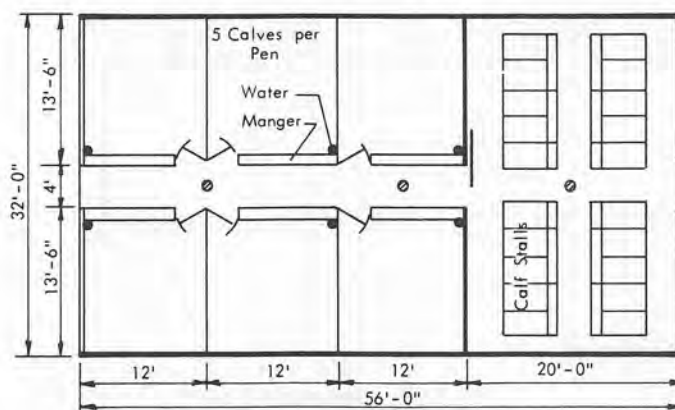


Fig 423-25. Calf barn—mwps-72341.

Cold Barn

Pens should be used so calf can move about to get out of drafts. Solid partitions will reduce drafts and provide isolation for calves. Temporary movable partitions facilitate cleaning when calves are removed.

Heat lamps plus a portable cover over part of the pen may be necessary during cold weather.

If water is to be provided in each pen, electric heaters will be necessary.

Provide hot and cold water, a drain, and storage space for utensils and supplies.

When calves are housed in open sheds, a manure pack can be started by older animals before cold weather.

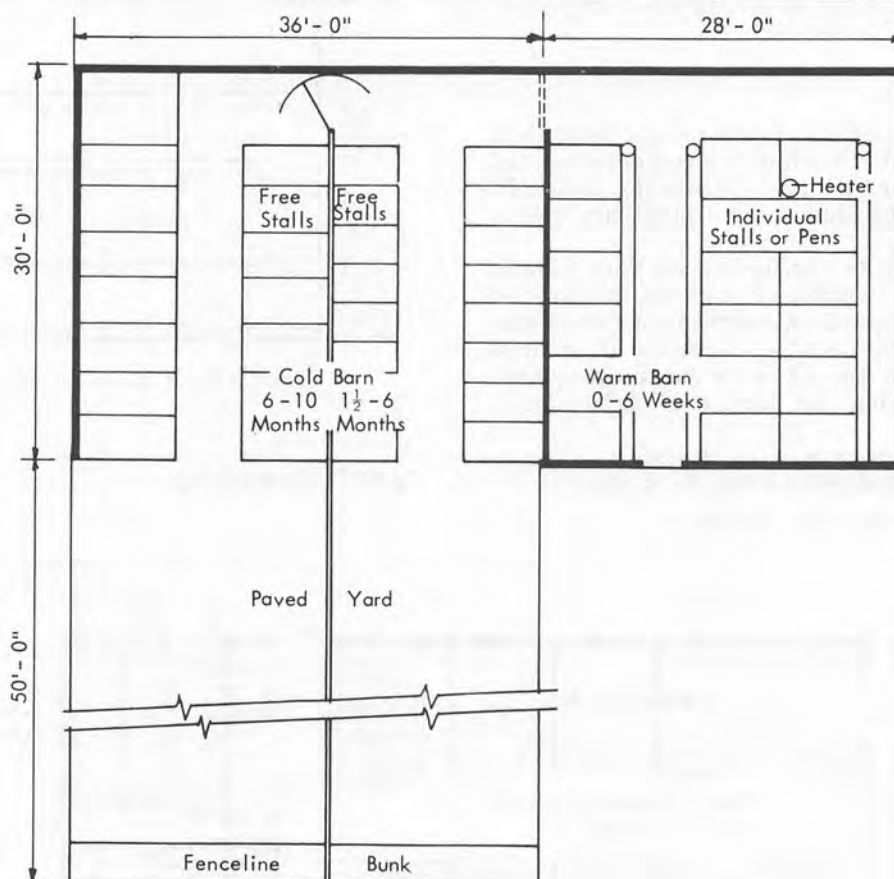


Fig 423-26. Calf and youngstock housing.
Michigan State U. Plan #723-CI-76

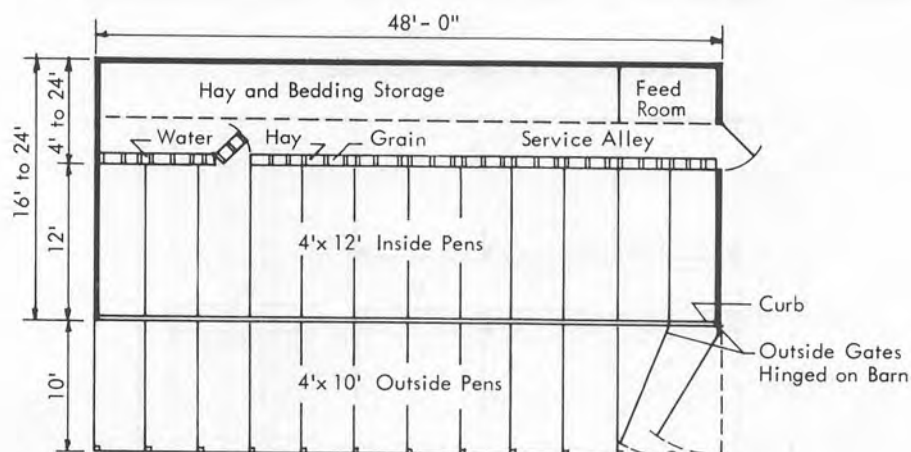


Fig 423-27. Open front calf barn.
U. of Illinois Plan No. 558

PENS

CALF, MATERNITY, BULL

Calves

Individual stalls or pens are preferred for calves up to 8 weeks of age or until calves are on solid feed to reduce danger of spread of disease or injury due to sucking. Tie stalls require less space, are easier to clean and require less bedding than pens.

Group calves when animals are too big for stalls or are on solid feed:

Maximum of 6 calves/pen.

Maximum age difference of 2 months.

Calves to 1½ months

Individual stalls 24" x 48". If slotted floors are desired, use no bedding and slot only the rear portion of the stalls. Provide shallow gutters to collect urine and washings.

Individual loose-run pens should be 20-25 sq ft. But, in group pens allow 15-20 sq ft/calf and one 18"-20" stanchion/calf.

Calves 1½ to 10 months—group pens

20 to 25 sq ft/calf.

20"-24" of stanchion space

Calves over 10 months—group pens

30-40 sq ft/calf

24"-30" stanchion space

All pens should have movable or swinging partitions so manure can be removed by machine.

Heifers, 10 months to freshening

Heifers are normally provided cold housing. Provide a bedded resting area:

Jerseys 30-45 sq ft/head

Guernseys and Ayrshires 35-50 sq ft/head

Holsteins and Brown Swiss 40-55 sq ft/head

Provide a feeding area separate from the bedded area. Feed outside or in open shed.

If cows are housed in stanchions, familiarize heifers with stanchions before they are heavy with calf.

Table 423-8. Maternity and bull pen sizes.

Maternity Pens (one per 20 cows)	
Jerseys	100 sq ft
Guernseys and Ayrshires	110 sq ft
Holsteins and Brown Swiss	120 sq ft
Bull Pens	
Jerseys	120 sq ft
Guernseys and Ayrshires	140 sq ft
Holsteins and Brown Swiss	160 sq ft

Table 423-9. Pen construction.

	Calf	Heifer	Maternity	Bull
Total height of partitions	4'	4½'	4½'	5½'
Width of gates	3'-3½'	3'-3½'	3½'-4'	3½'-4'

Alleys for animals should be at least 4' wide. Short feed alleys may be 2'-3' wide.

Watering

Automatic drinking cups are preferred—frostproof in a cold barn.

Water should be kept clean and fresh.

Top of drinking cups for calves should be 20" from floor; one cup/6 calves.

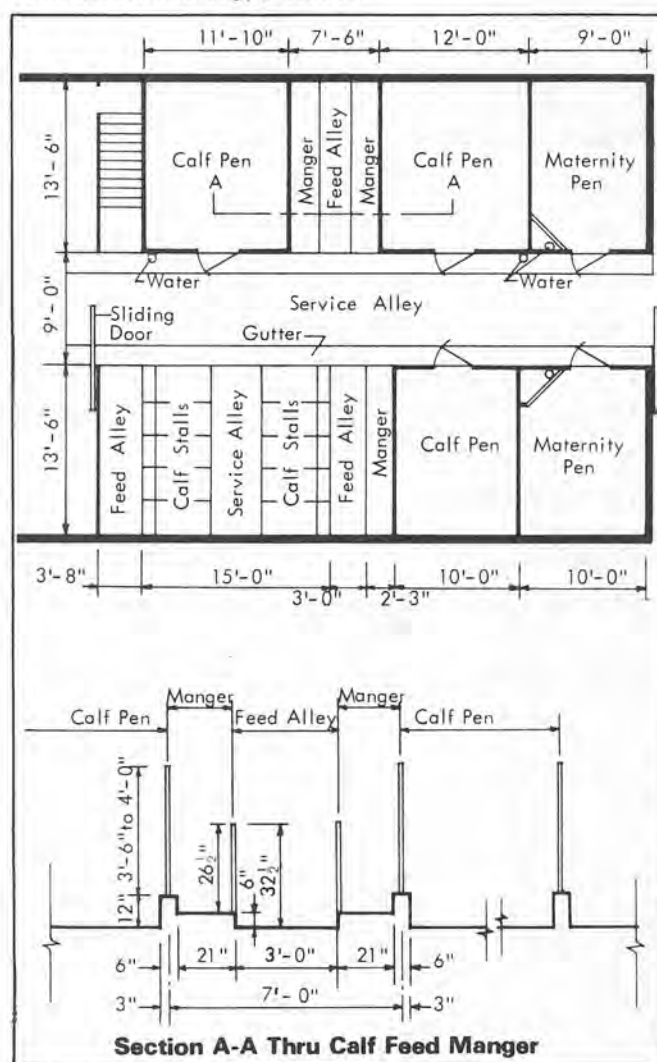


Fig 423-28. Pen layout—stanchion barn.

SECTION 4—DAIRY

4.1 Curves presented in Figs. 7-13 show weight versus age and physical dimensions versus weight for dairy cattle of selected breeds.

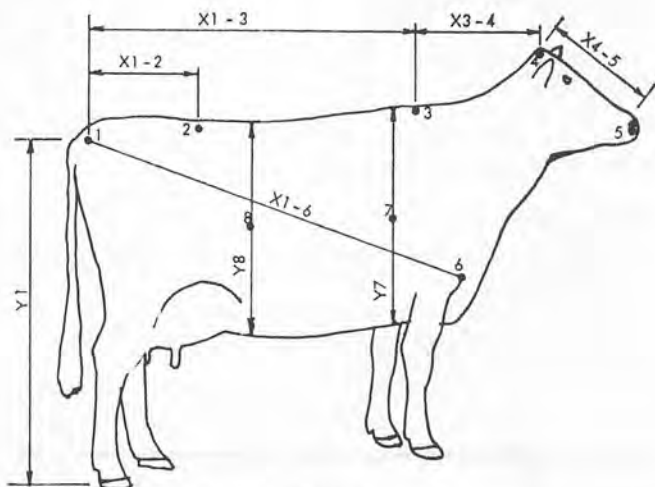


Fig 423-29. Dimensions of dairy cattle.

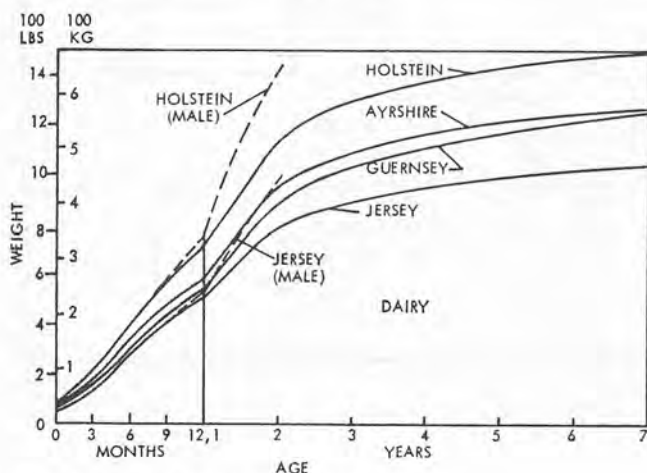


Fig 423-30. Weight versus age of dairy cattle.

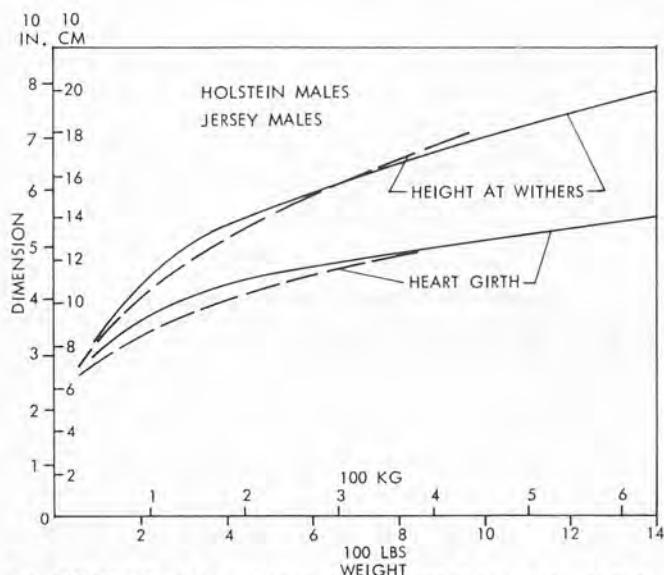


Fig 423-31. Physical dimensions versus weight of dairy males, birth to 2 years old.

4.2 Reference Points (See Fig. 7)

Height above floor (Y)

Y1 Height to pinbones (Y1), hips (Y2), and withers (Y3) are nearly the same for all breeds and ages. The pinbones are generally lower by up to 5 percent, especially in mature animals.

Lengths (X)

X1-6 Pinbone to front of shoulder (body)

X1-2 Pinbone to hip (rump)

X1-3 Pinbone to wither (back)

X3-4 Wither to pole (neck)

X4-5 Pole to muzzle (face)

Depths (Y)

Y7 Chest, at heart girth

Y8 Barrel

Depth at chest and barrel are nearly the same at birth. By six months of age the following approximations apply:

Y7 = Y8-3 cm for Holstein and Guernsey

Y7 = Y8-2.5 cm for Jerseys

Y7 = Y8-4.5 cm for Ayrshire

Circumferences (girths) (C)

C5 Muzzle

C7 Chest, at heart girth

C8 Barrel

Widths (Z)

Z1 Pinbones

Z2 Hips

Z4 Forehead

Z7 Chest, at heart girth

4.3 References:

Comparative Measurements of Holstein, Ayrshire, Guernsey, and Jersey Females from Birth to Seven Years, Nebraska Agricultural Experiment Station Research Bulletin 179, 1956.

Brody, S., Bioenergetics and Growth, Reinhold Publishing Corp., 1945.

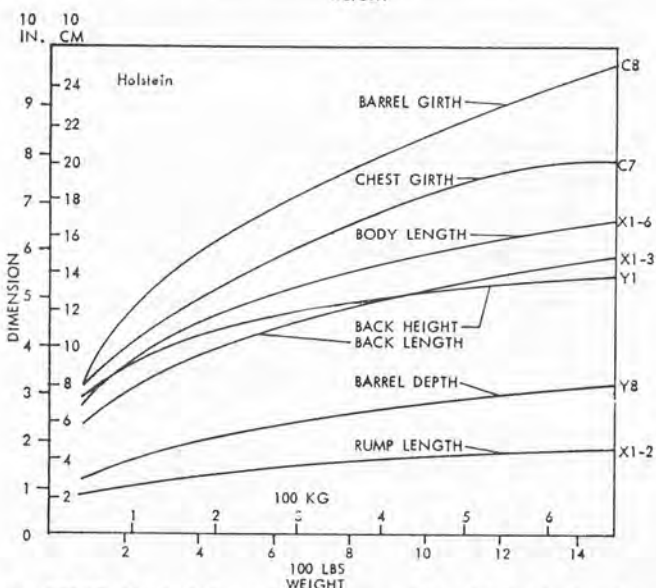
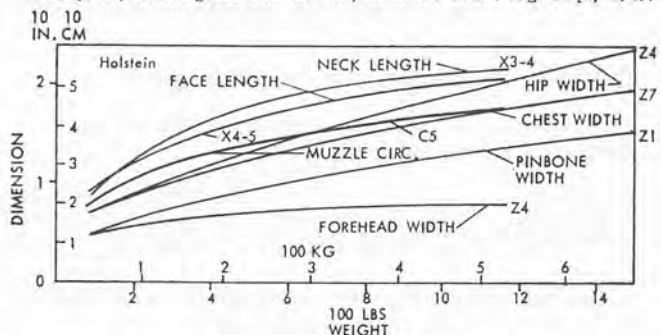


Fig 423-32. Physical dimensions versus weight of holstein females.

Table 423-10. Concentrates for dairy cattle.

	Milk Per Day		Concentrates Per Day*	
	lb	kg	lb	kg
	30	13.6	10	4.5
	40	18.1	15	6.8
	50	22.2	20	9.1
	60	27.2	25	11.3
	70	31.7	30	13.6
	80	36.3	35	15.9
	90	40.8	40	18.1
	100	45.4	unlimited	unlimited
Calves and heifers			2-4	0.9-1.8

Table 423-11. Roughages for dairy cattle.

Animal	Hay Equivalent Per Year		Hay Per Year		Silage Per Year	
	lb	kg	lb	kg	lb	kg
Cows weighing 1200 lb (545 kg) and producing 10,000 lb (4536 kg) of 4 percent milk	6500	2948	3200	1451	10000	4536
For each additional 100 lb (45.5 kg) increase in body weight	500	227	200	91	1000	454
Dairy heifers, 1-2 yrs	3300	1497	2000	907	4000	1814
Dairy calves, under 1 yr	2000	907	1500	680	1500	680

Table 423-12. Water for dairy cattle.

Class of Cattle	Condition	Water per Day	
		lb	kg
Holstein Calves	4 weeks of age	10-12	4.5-5.4
Holstein Calves	8 weeks of age	13	5.8
Holstein Calves	12 weeks of age	18-20	8.2-9.1
Holstein Calves	16 weeks of age	25-28	11.3-12.7
Holstein Calves	20 weeks of age	32-36	14.5-16.3
Holstein Calves	26 weeks of age	33-48	15.0-21.8
Dairy Heifers	Pregnant	60-70	27.2-31.8
Jersey Cows	Milk 5-30 lb (2-14 kg) daily	60-102	27.2-46.3
Holstein Cows	Milk 20-50 lb (9-23 kg) daily	65-182	29.5-82.6
Holstein Cows	Milk 80 lb (36 kg) daily	190	86.2
Holstein Cows	Dry	90	40.8

* Extracted with permission from The 1969 Agricultural Engineers Yearbook. The American Society Of Agricultural Engineers, Box 229, St. Joseph, Michigan 49085.

Table 1: Summary of the first section of the document.

Category	Item 1	Item 2	Item 3
Section 1	1.1	1.2	1.3
Section 2	2.1	2.2	2.3
Section 3	3.1	3.2	3.3
Section 4	4.1	4.2	4.3
Section 5	5.1	5.2	5.3
Section 6	6.1	6.2	6.3
Section 7	7.1	7.2	7.3
Section 8	8.1	8.2	8.3
Section 9	9.1	9.2	9.3
Section 10	10.1	10.2	10.3

Table 2: Summary of the second section of the document.

Category	Item 1	Item 2	Item 3
Section 11	11.1	11.2	11.3
Section 12	12.1	12.2	12.3
Section 13	13.1	13.2	13.3
Section 14	14.1	14.2	14.3
Section 15	15.1	15.2	15.3
Section 16	16.1	16.2	16.3
Section 17	17.1	17.2	17.3
Section 18	18.1	18.2	18.3
Section 19	19.1	19.2	19.3
Section 20	20.1	20.2	20.3

Table 3: Summary of the third section of the document.

Category	Item 1	Item 2	Item 3
Section 21	21.1	21.2	21.3
Section 22	22.1	22.2	22.3
Section 23	23.1	23.2	23.3
Section 24	24.1	24.2	24.3
Section 25	25.1	25.2	25.3
Section 26	26.1	26.2	26.3
Section 27	27.1	27.2	27.3
Section 28	28.1	28.2	28.3
Section 29	29.1	29.2	29.3
Section 30	30.1	30.2	30.3

CHAPTER 424 SHEEP

Introduction

Up-to-date sheep housing and related facilities are important structures: saving labor; protecting animals, feed, and equipment; and aiding effective management. Like machines, buildings need to be updated or replaced when their usefulness is reduced or lost by wear and tear, or when changes in farm production systems make them obsolete.

Increases in flock size and current economic and environmental factors encourage good management with well planned housing and facilities for ewe and feeder lamb operations.

In the North Central Region, sheep are most commonly provided dry, cold, solid-floor housing with outside lots. However, slotted floors have been successfully used in complete confinement barns. For lambing in cold weather, a well-protected area in cold housing or warm housing is provided.

In addition to shelter, needed facilities include: a management center, feed storage, feeders and waterers, creeps, lambing pens, shearing area, hospital area, and corral.

Sound and timely management decisions, based on selecting the best of several alternatives for each component, are required to obtain well planned sheep housing.

Data Summary

Feeder space

Group-fed:

16"-20"/ewe

9"-12"/feeder lamb

Self-fed:

10"-12" silage, 8"-10" hay/ewe

3"-4"/feeder lamb

Waterer space

Per automatic bowl

40-50 ewes or ewes with lambs

50-75 feeder lambs

Per ft. of tank perimeter

15-25 ewes or ewes with lambs

25-40 feeder lambs

Shelter space

Open-front building with lot:

10-12 sq ft/ewe

12-16 sq ft/ewe and lambs

6-8 sq ft/feeder lamb

Lot:

25-40 sq ft/ewe

25-40 sq ft/ewe and lambs

15-20 sq ft/feeder lamb

Solid floor (confinement):

12-16 sq ft/ewe

15-20 sq ft/ewe and lamb

8-10 sq ft/feeder lamb

Slotted floor confinement:

8-10 sq ft/ewe

10-12 sq ft/ewe and lamb

4-5 sq ft/feeder lamb

Water consumption per day

2 gal/ewe

2½ gal/ewe and lamb

1½ gal/feeder lamb

Feed requirements per day

Hay:

- 2½-4 lb/ewe, maintenance and early gestation—No supplement required

- 4-7 lb/ewe, late gestation and lactation—plus supplemental grain

Haylage:

- 5-7 lb/ewe, maintenance and early gestation—No supplement required

- 8-10 lb/ewe, late gestation and lactation—plus supplemental grain

Corn silage:

- 7-9 lb/ewe, maintenance and early gestation—plus protein and mineral supplement

- 12-20 lb/ewe, late gestation and lactation—plus protein and mineral supplement and occasionally grain

- 4-6 lb/feeder lamb, plus 1-2 lb/day grain and protein and mineral supp.

Grain:

- 3/4-1½ lb/ewe, late gestation and lactation

- 2-3 lb/feeder lamb, plus protein and mineral supplement

- 0.6-1 lb/lamb, creep feeding to weaning

Protein supplement:

- 1/8-1/4 lb/ewe, maintenance and gestation

- 1/4-1/2 lb/ewe, lactation

- 1/4-1/2 lb/feeder lamb

Provide lambing pens for:

10%-15% of 100-ewe flock

7%-9% of 600-ewe flock

4%-6% of 1000-ewe flock

Lambing pens (jugs) 4'x4'x30" or 4½'x4½'x36"; provide grain and water

Lamb creep space:

1.5-2 sq ft/lamb

Nursery pens for 2- to 4-day old lambs before putting into group pens:

about 16'x16' for 20 ewes and 30 lambs

Group pen size:

about 125 to 150 ewes with singles

about 60 to 75 ewes with twins

Manure production, raw waste, lb/day:

6 lb, or 0.1 cu ft per ewe

4 lb, or 0.065 cu ft per lamb

Warm housing:

Supplemental heat:

1000-2000 Btu/hr per 1000 lb animal wt.

Forced ventilation:

25 cfm/1000 lb animal wt continuous winter minimum rate.

200 cfm/1000 lb animal weight, summer rate.

Housing

Barns for sheep are related to two basic building shells: open-front buildings for minimal shelter, and completely enclosed buildings for maximum shelter. The usable space in either may be only the ground floor level, but depending on design and construction, either may include additional space overhead for hay, bedding, and feed storage.

Provide 8'-10' of headroom above floor level. Ventilation is essential in both open front and enclosed buildings to control moisture, modify temperatures, furnish fresh air, and remove gases and odors.

Floors may be packed earth, gravel, crushed rock, or concrete. A concrete floor is desirable in heavy traffic areas where mud causes problems, but is not necessary in pens. Use doors at least 8' wide x 8' high for tractor access.

Windows or plastic light panels in the walls, 3%-5% of the floor area, can supply natural light. Install artificial general lighting for night chores—one 100-watt lamp for each 400 to 500 sq ft of floor area. Provide electric outlets and line capacity for lambing pen heat lamps, heating and ventilating equipment, yard lights, and other electrical conveniences.

Consider insulating a portion of the sheep barn for lambing, shearing, hospital pen, and shepherd's room. The size of this warm insulated section depends on flock size, management, and your preferences. Ventilation fans are necessary in the warm insulated section.

Barns are usually one floor, clear-span construction for either open-front or enclosed buildings, although post and beam-supported roofs are not uncommon. Costly overhead storage is eliminated or minimized in one-floor buildings. Clear-span buildings are flexible for arranging pens and traffic lanes, are more adaptable to other uses, and make cleaning with mechanical equipment easier.

Types of Housing Environment

Generally, cold housing is used for ewes and feeder lambs. Warm housing is frequently used in cold climates for lambing. Cold and warm housing refer to winter conditions inside the sheep barn. Temperatures inside cold housing may be only slightly higher than outdoors. In warm housing, inside temperatures are maintained above about 45°F (7°C) and often at 50°-55°F (10°-13°C).

To provide a healthy environment, both cold and warm sheep housing require:

- A suitable site and construction.
- Ample light, and ventilation.
- Draft-free loose-run group pens.
- Warm or protected individual pens for lambing, with supplemental heat as needed.

- Good traffic lanes for handling materials and animals.
- Planned manure handling, and easy-to-clean pens and feeding facilities.
- Good housekeeping and sanitation, and dedicated management.

Cold Sheep Housing

Cold housing is usually adequate for sheep. It is used with existing or new barns that are either permanent or temporary buildings. Natural air movement is utilized for ventilation, and supplemental heating is limited to occasional use for cold weather lambing. Heat lamps are the most common method of providing supplemental heat.

Cold housing may be open-front or partially enclosed. Provide adequate ventilation, and keep the animals clean, dry, and out of drafts.

Insulation is added to cold sheep barns primarily to control condensation and frost formation on inside wall and roof surfaces and to resist high summer temperatures. Table 424-1 lists the "R" values necessary to prevent moisture condensation when building is about 0°F. For example, if the difference between inside and outside temperatures is 10°F, (outside, -10°F; inside, 0°F) and indoor relative humidity is 90%, the total "R" value of the roof or wall must be greater than 3.4 to prevent condensation. From Table 214-1, 1/2" extruded polystyrene (2.63), and 2 air films (0.68 + 0.17) = 3.48. Table 424-1 illustrates that the tighter a producer closes a cold building to get a larger temperature differential, the more insulation he needs to prevent condensation and frost formation.

Table 424-1. Insulation "R" values required to prevent condensation in cold housing.

Do not use these insulation levels for designing warm housing.

Relative Humidity	Difference Between Inside & Outside Temperatures					
	5	10	15	20	25	30
60	0.36	0.73	1.09	1.46	1.82	2.18
70	0.51	1.02	1.53	2.04	2.55	3.06
80	0.82	1.64	2.46	3.28	4.10	4.92
85	1.13	2.27	3.40	4.53	5.67	6.80
90	*1.70	*3.40	5.10	6.80	8.50	10.20
95	3.40	6.80	10.20	13.60	17.00	20.40

* a good design range

Warm Sheep Housing

Warm housing is seldom used for sheep except in the lambing area. Warm housing refers to a tightly constructed and insulated building

equipped and managed to maintain inside temperatures 15°-30°F above freezing (8°-17°C) in coldest weather. Provide for temperature and moisture control:

- Insulation in the walls and ceiling, and the foundation.
- Limited door and window openings to reduce heat losses.
- Vapor barriers to protect the insulation from moisture.
- Fans to move air to control moisture, odors, and temperature.
- Adjustable vents or other air inlets and outlets for winter and summer ventilation.
- Supplemental heat if needed for temperature and moisture control.

Open-Front Barn With Lot

This system works best where annual precipitation is less than 30" per year. At higher rainfalls, more care is required to maintain lot slopes and surfaces and to control surface drainage. Sheep are relatively intolerant of mud, so year around dry-surface access to shelter, feed, and water are needed.

These five arrangements indicate open-front buildings with clear-span construction. A small amount of ceiling insulation is desirable to control winter condensation and summer heat. The building floor need not be concrete; 2"-4" deep crushed limestone works well, is inexpensive, and easily replenished. Sand, gravel or compacted clay are also used. Lots should have compact surfaces and be well-drained. Use stone or gravel where needed to maintain slopes for adequate drainage and to reduce mud. Pave along feeders, around waterers, and along the open building front if wet conditions are troublesome.

Fig 424-1 shows grain self-feeders for feeder lambs. The open-front barn protects both feed and lambs from bad weather. To mechanize filling the self-feeders, run a conveyor the length of the barn with a feed drop at each feeder.

Fig 424-2 shows ewe feeding layouts. Fenceline bunks are shown in Fig 424-2a, b, and c, and a mechanical bunk in Fig 424-2d. Provide bunk space for all animals to eat at one time, 16"-20"/ewe. Set the fenceline bunk out slightly from the barn for easy feed wagon access. Leave space at the low end of the lot for surface drainage. A central drive through the open-front barn enables the lot to be shorter, but prevents blocking the ewes away from the feeding area inside the barn. Fig 424-2c.

Fig 424-2a is a typical open-front barn with a large lot of about 40 sq ft/ewe. In Fig 424-2b, the

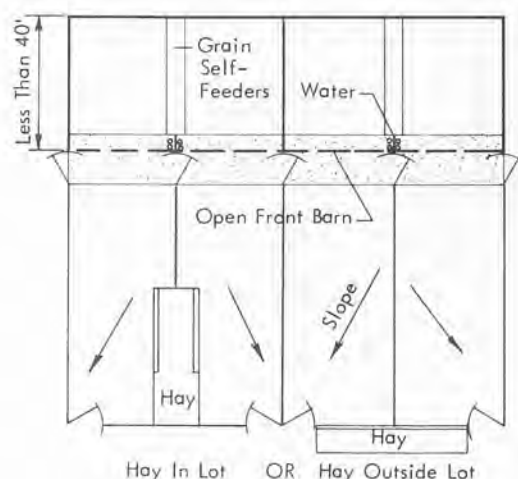


Fig 424-1. Lamb feeding layout.

Open-front building space: 6-8 sq ft/feeder lamb; lot space: 15-20 sq ft/feeder lamb; self-feeding space: 3'-4"/feeder lamb.

area of the lot is about twice the barn area; 25 sq ft/ewe is adequate with good lot drainage and relatively low rainfall.

When mechanical equipment is used, providing adequate bunk space to feed a large flock of ewes all at one time is expensive. Fig 424-2d shows an arrangement for mechanical feeding one pen at a time. Ewes are run from one pen into the feeding area and then back into their pen, utilizing the same equipment to feed several groups. Moving ewes requires more labor than fenceline feeding.

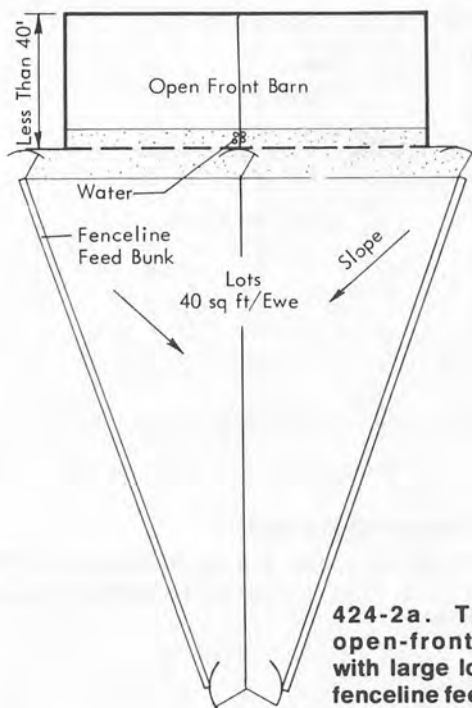
Solid Floor Confinement Barn

Outdoor feeding offers little weather protection for the operator or the flock. Feed in open bunks is wet by rain and blown away by wind; snow and ice collect in feedbunks, and grain, hay and silage freezes. Outside space for lot arrangements may be inconvenient and expensive. Soil type, slopes, climate, or pollution from lot runoff may prohibit satisfactory operation of lots. A confinement barn can relieve these problems.

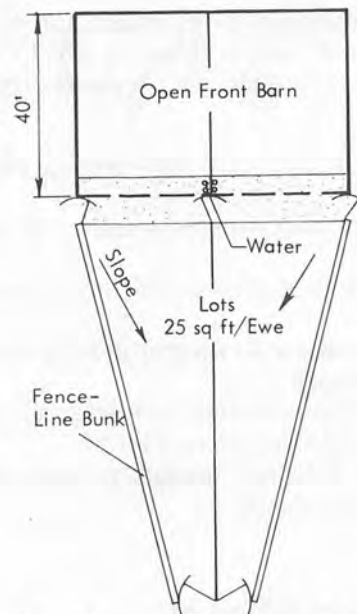
Fig 424-3a shows an open-front confinement barn with self-feeding. Provide four self-feeders for each pen of 50 ewes. A mechanical feedbunk down the center of the barn can replace the conveyor and self-feeders if silage is to be fed.

Fig 424-3b shows an open-front confinement barn with an inside feed alley the length of the building. Silage is distributed with an unloading wagon.

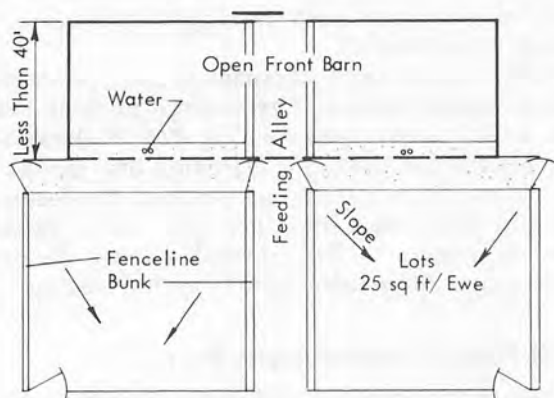
Lightly insulate the roof of an open-front building to prevent condensation. Provide ventilation with eave inlets and adjustable doors in the back wall and a continuous ridge opening.



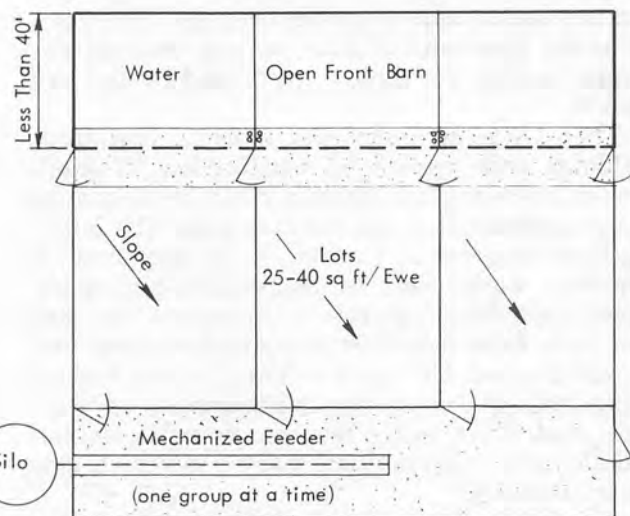
424-2a. Typical open-front barn with large lots and fenceline feeding.



424-2b. Open-front barn with small lots and fenceline feeding.



C. Open-front barn with small lots and fenceline feeding.



424-2d. Open-front barn with lots, showing mechanized feeding area for individual lots.

Fig 424-2. Ewe feeding layouts.

Open-front building space: 10-12 sq ft/ewe; feeding space: 16"-20"/ewe; lot space: 40 sq ft/ewe with average lot conditions: 25 sq ft/ewe with good lot drainage and relatively low rainfall.

Slotted-Floor Confinement Barn

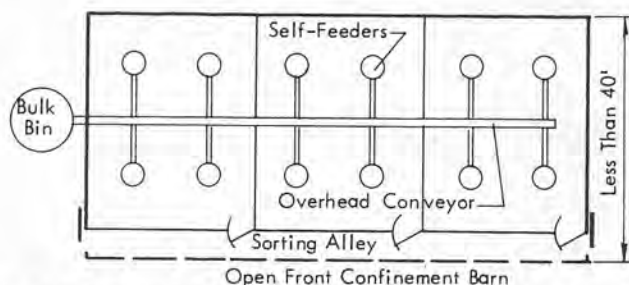
A confinement barn with slotted floors offers clean, dry floors with minimum cleaning labor. A building with slotted floors is only half the size of an equivalent building with solid floors. Reduced building size helps pay for slotted floors.

Fig 424-3c shows an open-front slotted-floor sheep barn with a drive-in manure pit. Locate the barn on an east or south slope; the pit can be en-

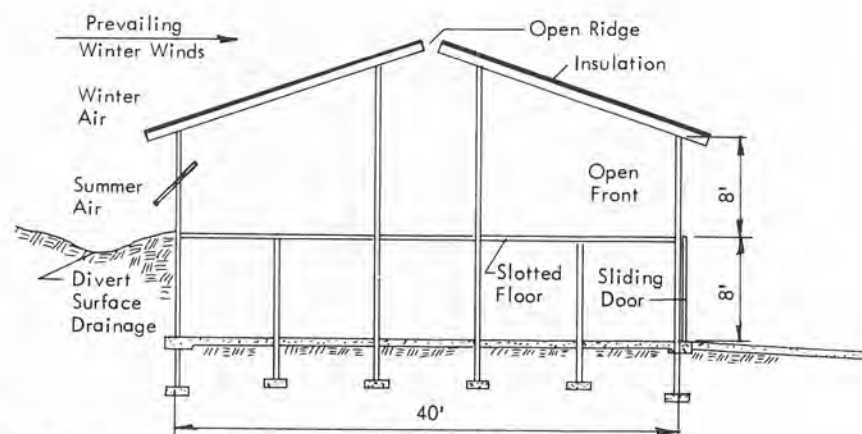
tered from the ground level for cleaning, but the high wall is protected from winter winds. When the east side of the barn is open; install adjustable eave openings on the west and a continuous vent at the ridge. During hot weather, open manure doors for additional ventilation.

Slotted Floors

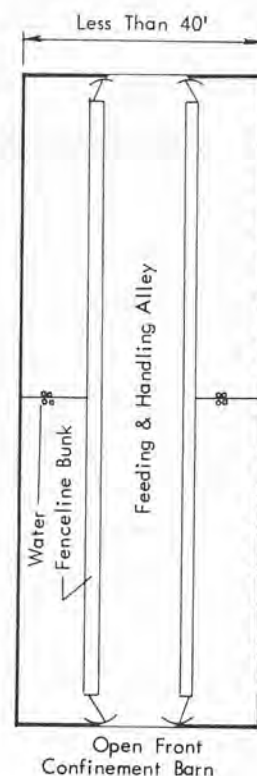
Consider slotted floors for intensive production units. They require no bedding, less labor and



424-3a. Open-front, solid floor, confinement barn, showing mechanized self-feeding for ewes or lambs.



424-3c. Slotted-floor confinement barn with underfloor cleaning.



424-3b. Open-front, solid floor, confinement barn with inside fenceline feeding.

Fig 424-3. Confinement feeding layouts.

Slotted floor space: 8-10 sq ft/ewe, 10-12 sq ft/ewe + lamb, 4-5 sq ft/feeder lamb. Solid floor space: 12-16 sq ft/ewe, 15-20 sq ft/ewe + lamb, 8-10 sq ft/feeder lamb. Group feeding space: 16"-20"/ewe, 10"-12"/feeder lamb.

space than solid floors, and provide better summer comfort. Lambs confined on slotted floors from birth to market gain equally well with similar feed requirements; internal parasites can be controlled without anthelmintics (drenches). Problems may include temporary ewe lameness, shortage of feeder space and more expensive buildings.

Wood, concrete, steel grids, and expanded metal have been used. Sheep are more sure-footed and hooves wear more evenly on $\frac{3}{4}$ " 9-gage, expanded metal than on other floor materials. To prevent hoof damage in large pens, set the long axis of diamond-shaped openings across the short pen dimension so the animals cannot run in the direction of the long openings.

Sheep also perform satisfactorily on steel grids and wood or concrete slats. Wood and concrete slats clean well while manure tends to freeze and build up on the steel grids. Fleeces become manure stained on concrete slats and steel grids. Humid

weather may cause poor footing on steel grids. Expanded metal slats with grooved tops improve footing, but trapped urine causes soiled fleeces. Wood slats may warp and have poor durability. Young lambs catch their hooves in the irregular slots between wood slats. Run slats parallel to feeders.

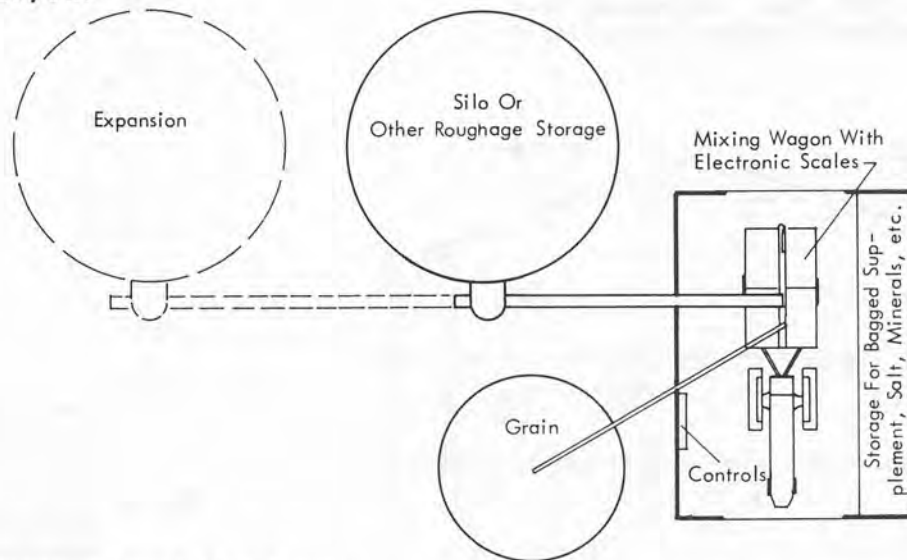
Manure Management

Management of sheep wastes involves environmental factors such as preventing water pollution and controlling odors and flies. When planning a waste management system, consult your state pollution control agency to assure compliance with state and federal regulations.

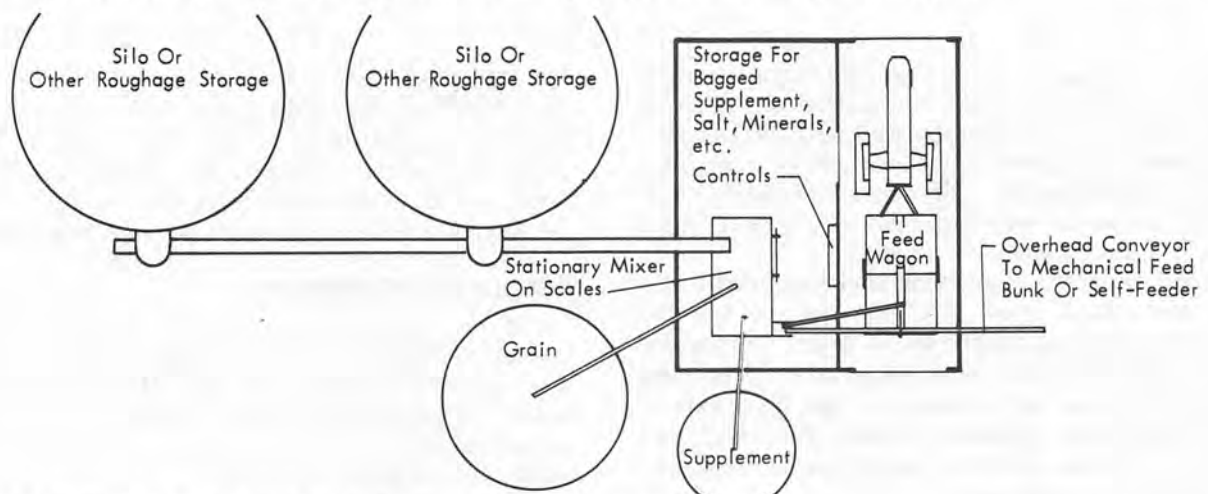
Unbedded sheep manure has a moisture content of about 75% and is handled as a solid. It must be diluted by about 2 parts water to one part manure to be handled as a liquid, making liquid handling impractical except for early weaned lambs on a liquid diet.

Table 424-2. Manure produced per 1,000 lb of sheep.

Raw manure, lb/day	40
cu ft/day	0.6
cu ft/yr	226
tons/yr	6.8
Total solids, lb/day	10.0
Volatile solids, lb/day	8.5
Biological Oxygen Demand (BOD ₅), lb/day	0.9
Nitrogen, % total solids	4.5
lb/yr	160
Phosphorus, % total solids	0.66
lb/yr	24
Potassium, % total solids	3.2
lb/yr	120

Feed Center Layout**Fig 424-4. Feed center layout for feed wagon.**

Fenceline bunks or widely separated self-feeders suggest a feed wagon for metering and mixing feed. You can meter by batching components over a platform scale and mixing in the feed wagon. A mixing wagon with electronic scales can accurately meter ingredients, and then mix and deliver them. The building provides storage for the feed wagon and tractor, and protects the conveying equipment, bagged feed, and loading area. The storages shown are for silage, pelleted feed, grain, or supplement; size them for the number of sheep fed and the frequency of filling. Allow for expansion and easy access for transporting feed and filling silos and bins.

**Fig 424-5. Feed center layout for feed wagon and mechanical conveyor.**

If both fenceline bunks and tightly grouped self-feeders or a mechanical feed bunk are used, the feed center needs to provide for both feed wagon and mechanical conveying. The ingredients are metered in batches into a stationary mixer over an electronic or platform scale. From the mixer the feed goes either into the feed wagon or is conveyed directly to self-feeders or a mechanical feed bunk. The rest of the system is similar to Fig 424-4.

SHEEP FACILITY LAYOUTS

Lamb & Nursing

Fig 424-8 to 424-13 are layouts for producers with ewe-breeding flocks. Provisions are included for ewes during gestation, lambing, and nursing. After weaning, several alternatives are common:

- If ewes are put on pasture, lambs are fed in the facility, operation calendar, Fig 424-6. Or, lambs may be fed on pasture or sold as feeder lambs.
- If ewes are kept in the unit after weaning, lambs are finished for market in a separate unit, or are sold as feeder lambs.

A multiple lambing schedule, Fig 424-7, utilizes facilities best when large flocks are confined to the lots year-round.

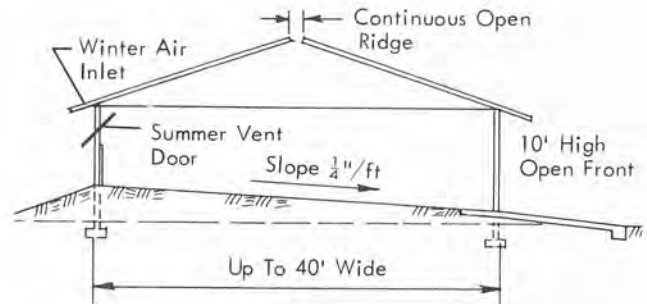
In large units, ewes are typically held in open lots during gestation and moved to smaller group pens ("drop pens") just before lambing. Each ewe, just prior to or after lambing, is put into a lambing pen ("jug"). After 1 to 3 days the ewes and lambs are moved to group pens, 50 lambs or less, until the lambs are about 10 days old. Ewes with twins and singles are then separated and put into large pens, 200 lambs or less, until weaning.

The ewes with twins require a better ration for higher milk production than those with singles.

Most sheep are housed in open-front buildings. Clear span construction permits rearranging space

without major building changes. Natural ventilation usually keeps inside temperatures a few degrees cooler in hot weather, and a few degrees warmer in cold weather, than outside temperature extremes (called "cold housing").

The barn floor is sloped towards the open front $\frac{1}{4}$ "/ft and the concrete apron along the open front is sloped $\frac{1}{2}$ "/ft.



Note: Sizes of rooms and pens are shown within the recommended ranges and are approximate. Where room or pen sizes are labeled, dimensions are in feet with the horizontal dimension shown first. For example, in Fig 424-9 the feed room is "8x12"—it is 8' left-to-right and 12' top-to-bottom.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lamb	←→											
Creep Feeding		←→										
Weaning				X								
Feed Lambs (finishing)				←→								
Pasture Ewes				←→								→

Fig 424-6. Operation calendar, early lambing.

Red Flock Green Flock	Year 1												Year 2											
Management	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Lambing																								
Creep Feeding																								
Weaning																								
Lamb Feeding																								

Fig 424-7. Two-year operation calendar, multiple lambing.

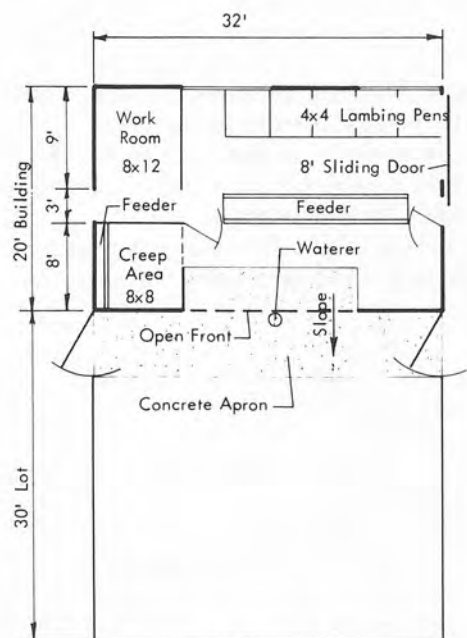


Fig 424-8. 30 ewes, inside feeding.

Movable pens, creeps and feeder permit flexibility in space use.

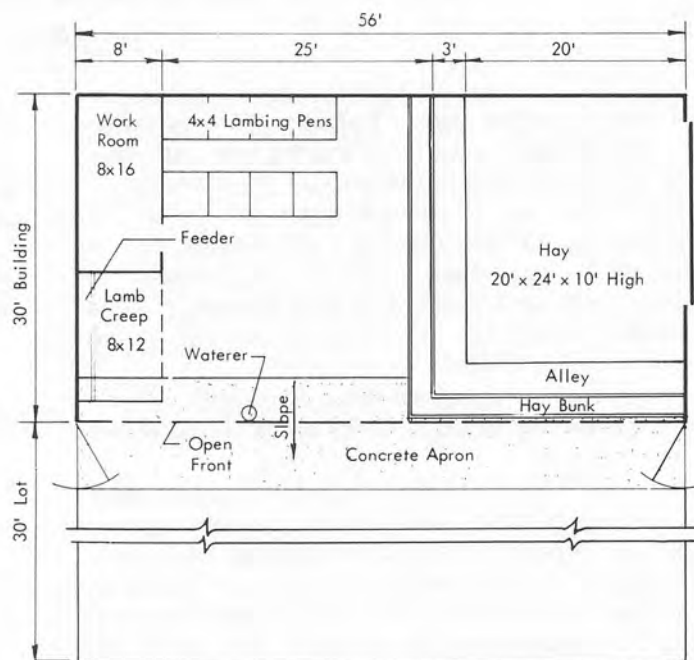


Fig 424-9. 50 ewes, inside feeding.

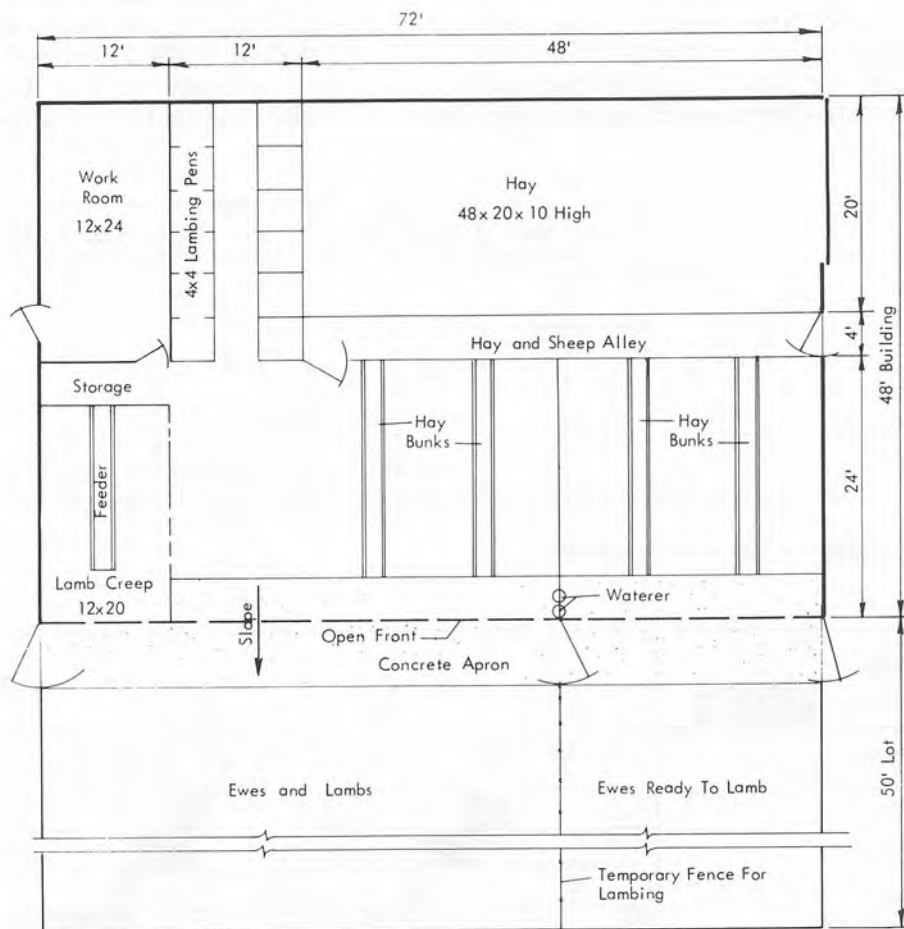


Fig 424-10. 100 ewes, inside feeding.

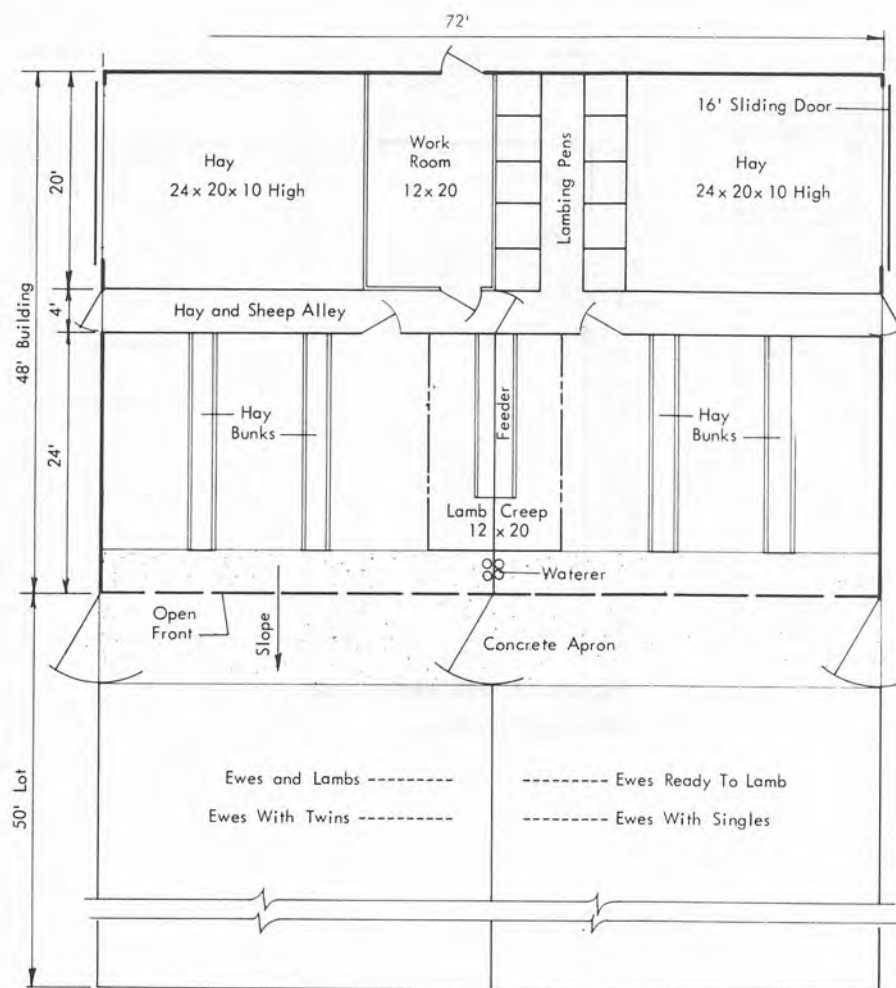


Fig 424-11. 100 ewes, inside feeding.

Two pens allow separation of twins and singles after lambing.

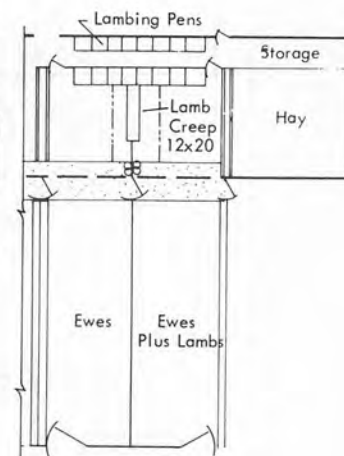
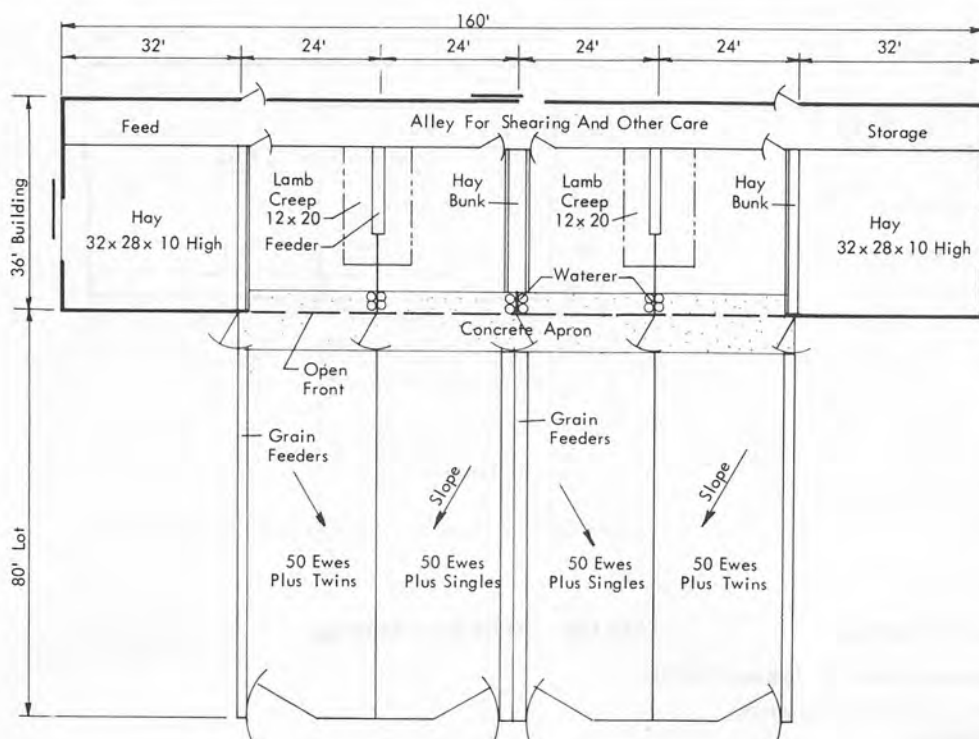


Fig 424-12. 200 ewes.

Ewes in groups of 50 are self-fed hay and hand fed grain and silage. Pens allow for separation of twins and singles after lambing.

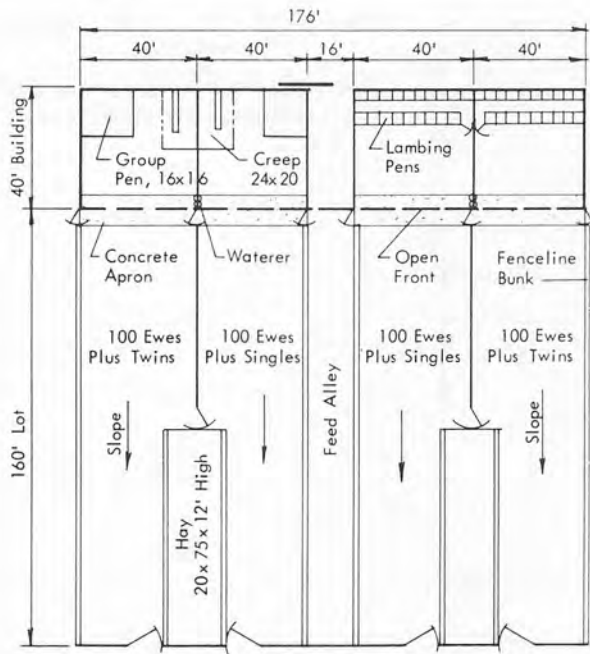


Fig 424-13. 400 ewes.
Once a year lambing.

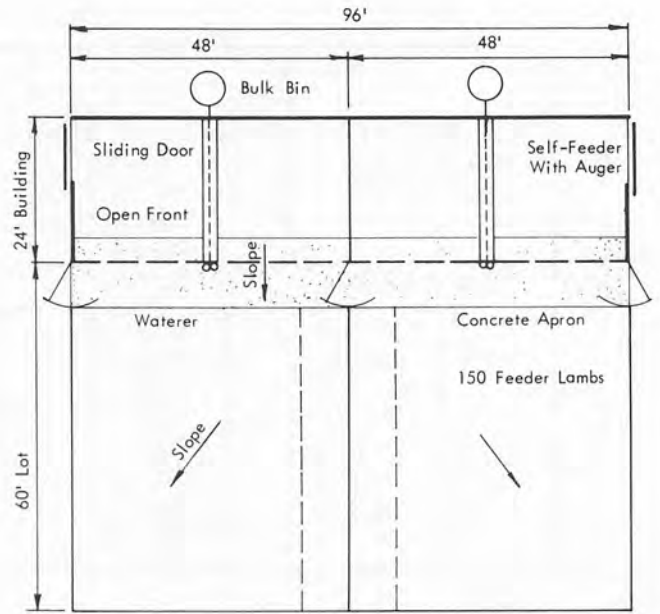
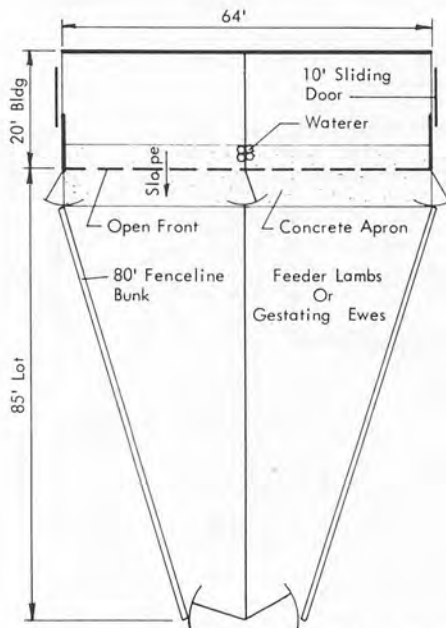
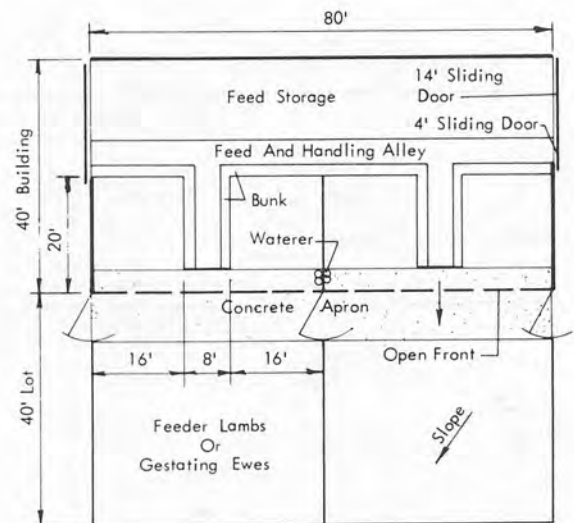


Fig 424-14. 300 feeder lambs.
Inside self-feeding.



424-15a. Outside fenceline feeding.



424-15b. Inside bunk feeding.

Fig 424-15. Group feeding, gestating ewes, or feeder lambs.
Each pen holds 55 to 65 ewes or 80 to 100 feeder lambs.
Separate facilities are needed for lambing.

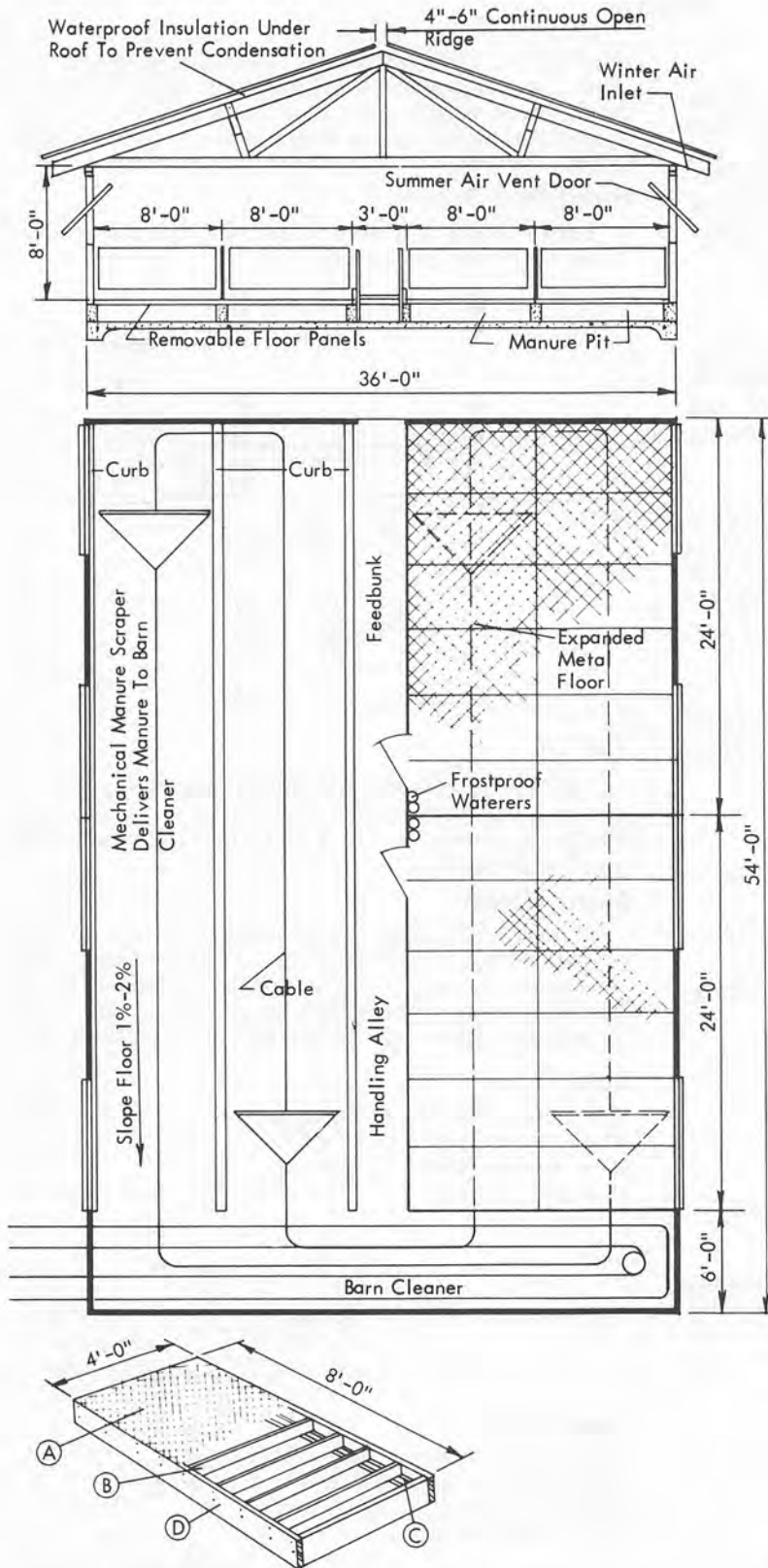


Fig 424-16. Slotted-floor confinement sheep barn.

Removable panels provide slotted floor over shallow pits cleaned with mechanical scrapers. Barn cleaner removes wastes from building. Capacity: up to 200 ewes @ 8-10 sq ft; up to 400 lambs @ 4-5 sq ft.

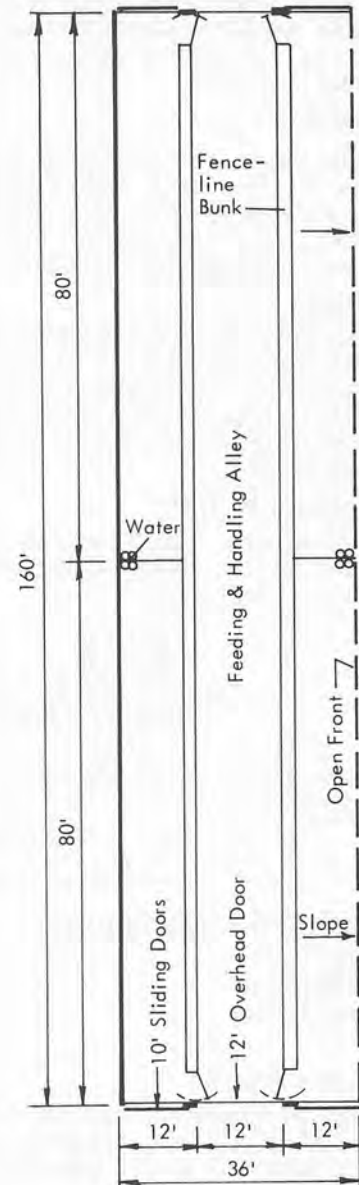


Fig 424-17. Solid-floor confinement sheep barn.

An open-front building with inside fence-line silage feeding. Capacity: 50-65 ewes @ 12-16 sq ft; 80-100 feeder lambs @ 8-10 sq ft.

Bunks

Feeding

Feeding space per sheep is determined by the size of the sheep, and the number of sheep that eat or drink at one time.

If all sheep eat at the same time allow 16"-20" of bunk space/ewe, 9"-12"/feeder lamb. If feed is always available allow: 10"-12"/ewe for silage; 8"-10"/ewe for hay; 3"-4"/feeder lamb; and 1"-1½"/lamb in a creep.

Orientation

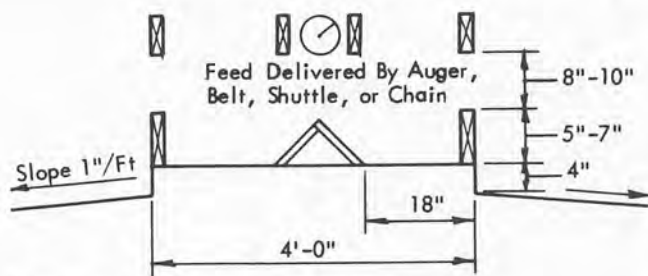
Orient bunks N-S to NE-SW with the buildings or silos on the north end. Provide drainage diversion on east or west facing slopes. Bunks should not block cross drainage on lots. Run bunks up and down the slope when possible.

Pavement

Pave around feeding and watering facilities where the soil type, rainfall or experience show it is needed to prevent problems with mud. Gravel or compacted clay is often adequate surfacing for sheep. Provide walkways from barns to feeding and watering areas.

Mechanical Bunks

Sheep usually feed from both sides. The bunks can serve as lot dividers. The feed center should be near the feeding line.

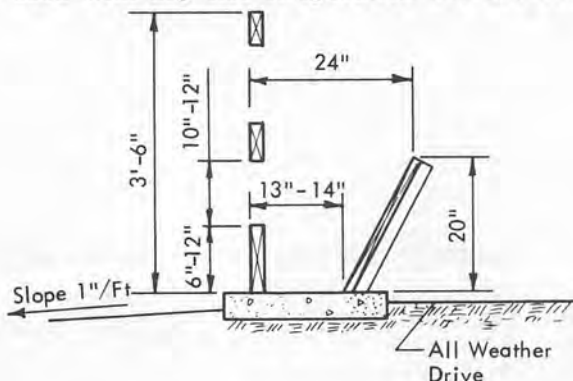


Throat Height, Maximum

15" ewe
13" feeder lamb
10" creep feeder

Fenceline Bunks

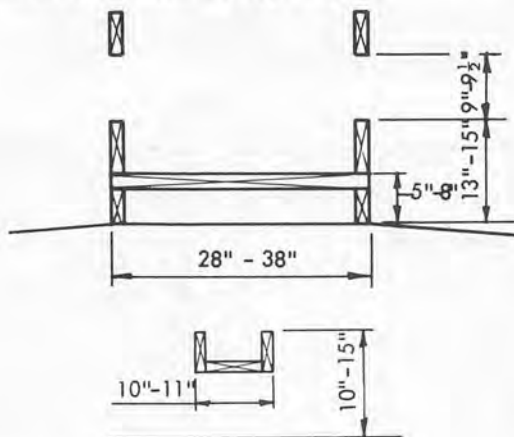
Sheep feed from one side. The bunks are usually filled with an unloading wagon or truck. They can be used with any size of operation and are easily



lengthened. Feeding drives take a lot of space, and must be surfaced for all-weather use. Twice as much bunk length (but not twice as much cost) is required as for bunks where sheep feed from both sides.

Hand-Fed Bunks

Small flocks are often hand fed. Locate feeders in an area that can be kept dry.



Apron

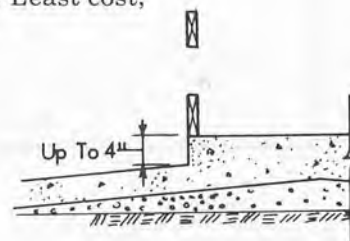
Provide a well-drained apron sloped 1" per foot away from feeders and waterers. If paved, a 6' width is adequate. If gravel or clay, somewhat more is desirable.

Floor Height

Indoor hay mangers are commonly only an inch or two above the sheep's feet. Outdoor bunks may be raised to help keep sheep and dirt out of the bunks, and so that sheep standing on soil, snow or manure don't eat below the level of their feet.

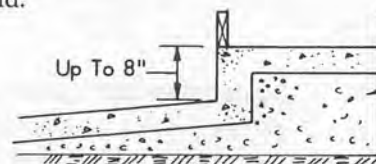
Low Floor

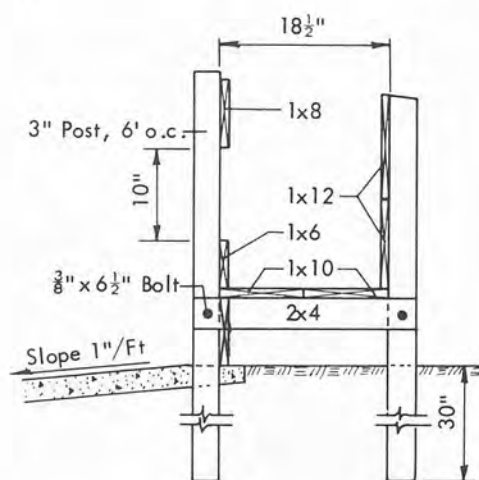
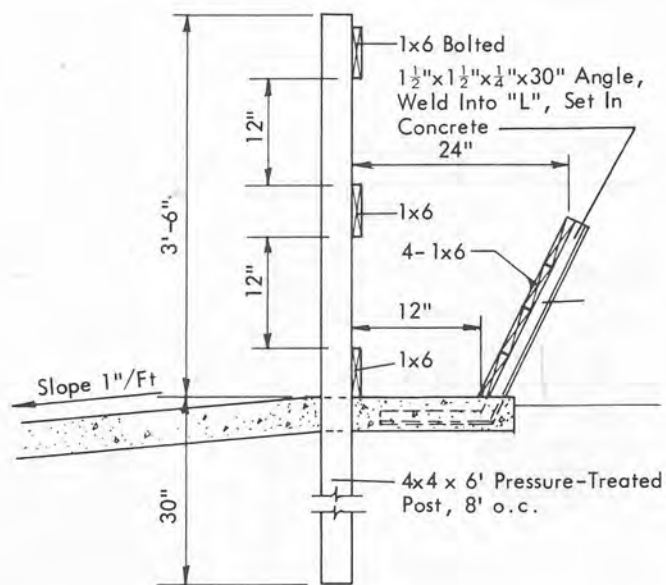
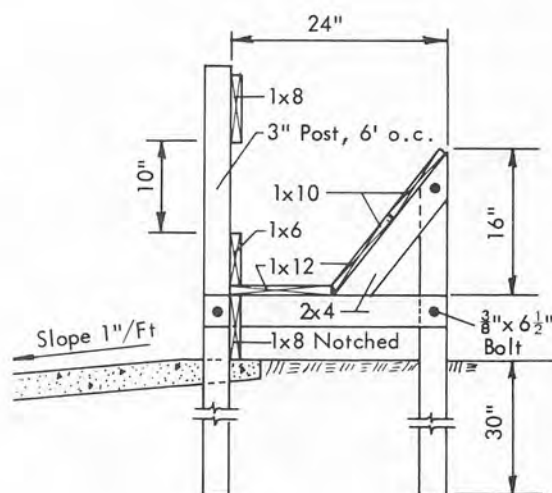
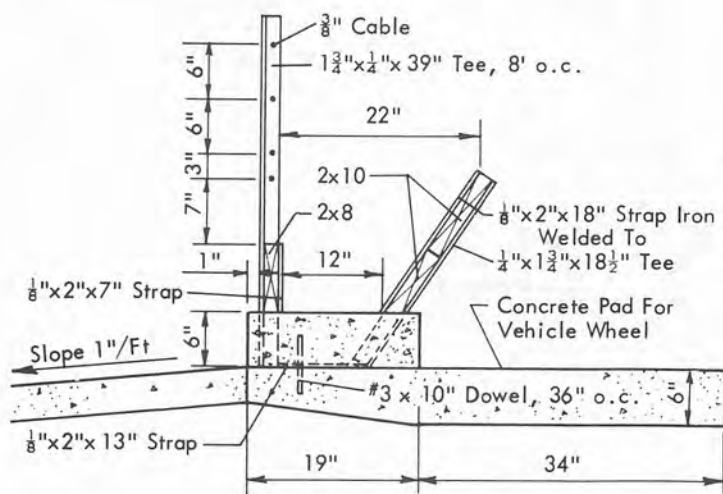
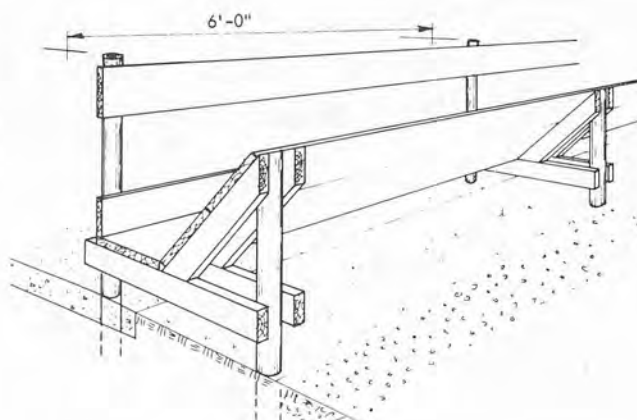
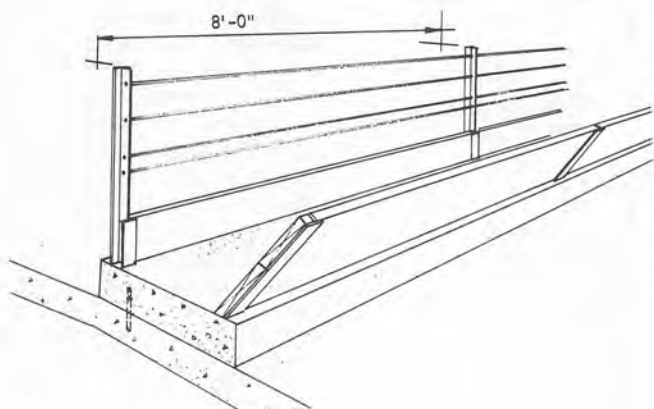
Used indoors. Used outdoors where area next to bunk will be more or less clean. Least cost, easiest to build.

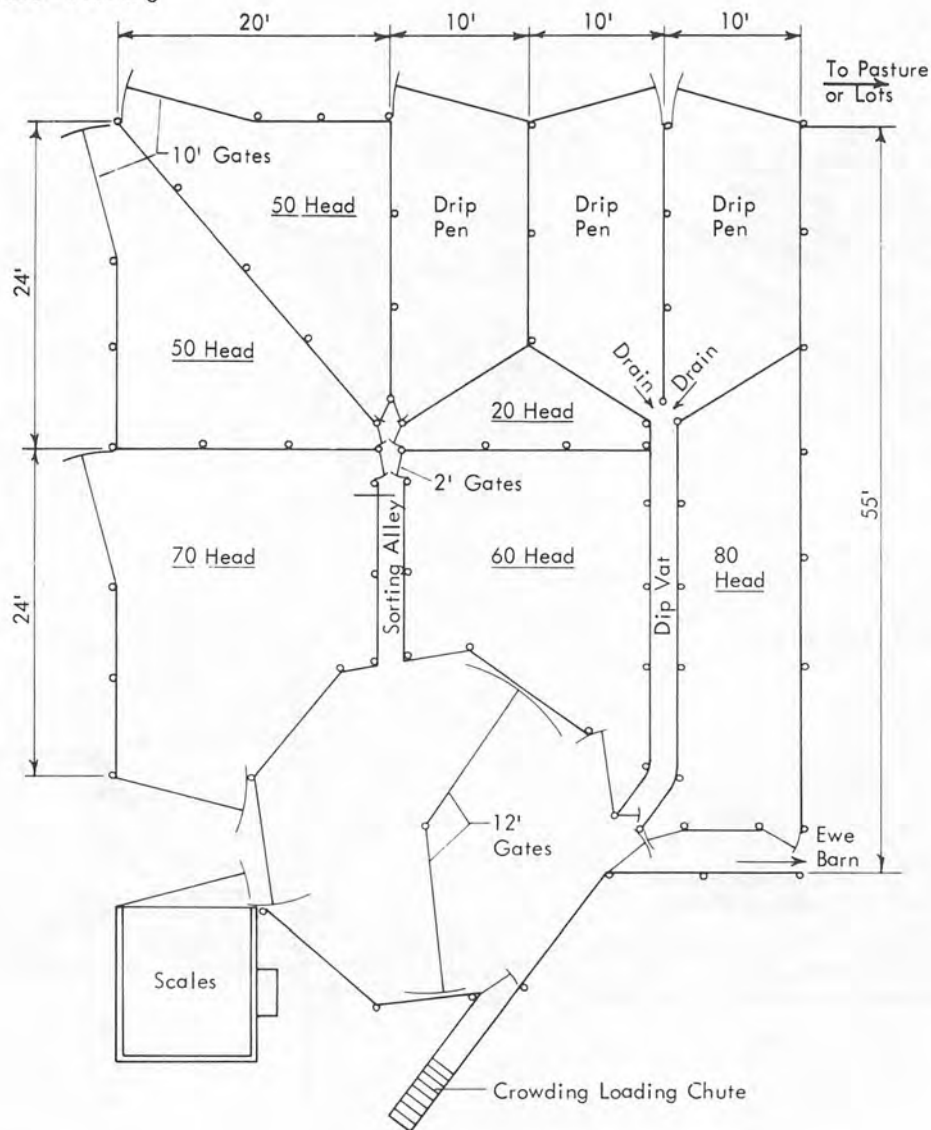


Raised Floor

Used where frozen manure, etc. may collect or where wood framing makes a higher bunk floor easier to build.







Corrals

Arrange corrals to take advantage of sheep's natural tendency to run in certain directions. Sheep in a corral run more easily away from the sun or toward their pasture. If neither of these two routes is open, they go toward other sheep or where they entered the corral. If one animal disappears around a corner, others will try to follow.

Corral space requirements:

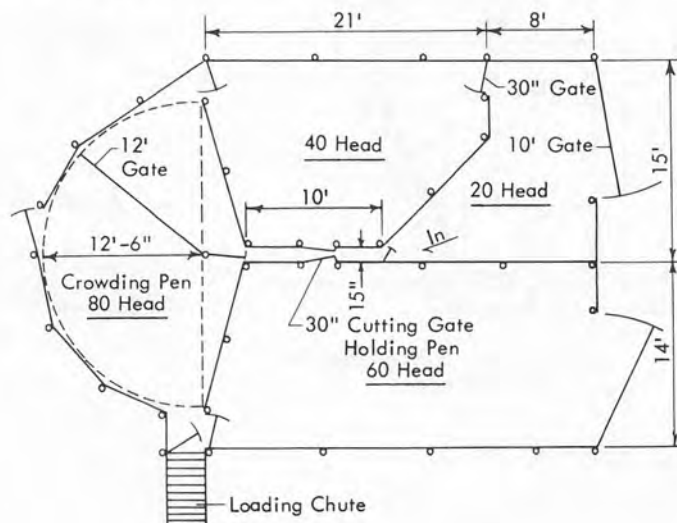
6 sq ft—breeding ewes with lamb and in the wool

5 sq ft—dry ewes

10 sq ft—ewes with 100 lb. lamb

4 sq ft—feeder lambs

Layout For 400 Head



CHAPTER 425 HORSES

ESSENTIALS FOR PLANNING

Here is a listing of some planning elements to check, decide on, or determine before moving on to detailed planning or starting the project. The more you know in advance, the better you'll be able to plan and to avoid or cope with difficulties that might occur unexpectedly later.

- Look into building codes, zoning regulations, and any other local restrictions that may affect development, construction, or use of the facilities.
- Collect ideas on horse facilities from publications, tours, visits to existing layouts, and from experienced horsemen, professional managers, etc.
- Choose a style for the barn or other buildings that fits the site and is in harmony with the surroundings.
- Decide on the number of animals to be handled and on how they'll be housed and managed.
- Determine the total amount of barn space needed under roof to stable and care for the animals. Basic space needs are for stalls, traffic lanes, and storage of feed, tack, and equipment. But include, also, special-purpose features: wash rack, trailer storage, breeding area, show stable, riding arena, rest space, and other areas needed under the same roof.
- Figure the amount of space needed under roof for separate but associated buildings; for example, open shelters, riding arena, sales barn, training barn, equipment storage, exercise area, hay and feed storage, office and lounge, and other areas (including living quarters if needed).
- Determine the amount of space needed for open and fenced areas: lanes and roads, outside lots and corrals, exercise areas, parking space for trailers and other vehicles and equipment, special events, and distance between buildings for pleasing appearance, fire protection, and future expansion.
- Compare alternative housing arrangements and management methods and select those most suited to your situation.
- Investigate methods and plan for inoffensive manure storage and disposal.
- Find out what fire protection is available, and modify plans accordingly for added protection or fire control if necessary.
- Review your budget allocation, placing priorities on necessities, conveniences, over-all desires, and frills in that order.

Once you've done these things, it's time to determine the size needed for the whole layout. Exclude family housing, large pastures, and crop and other land not directly associated with the stabling and facilities complex.

The size of the total layout is determined by the land area covered by the necessary buildings and the directly related open and fenced areas. This provides the basis for establishing the total land requirement. Large new and expanding horse farms may require sizable acreages, but only a small acreage may be needed for the building site and

an exercise area for a new small spread. (If an existing building is used for housing only, remember that space for an exercise area may be needed.)

The information gained in determining space requirements for the present, as well as possible future expansion, can be used for developing completely new layouts. Pertinent parts also can be selected and used for expanding present layouts or starting ones that incorporate existing buildings.

CODES AND REGULATIONS

Early in the planning stage, check to find out what effects various regulations and restrictions may have on the proposed project. Society places certain limitations on ownership, development, and use of property.

Zoning regulations, building codes, and sanitary regulations have come along with the encroachment of urban areas into what once were unrestricted rural areas. Many of these regulations now are on a county, state, or national basis, and are intended to regulate property uses considered detrimental or adverse to public welfare. Generally, building codes set construction standards, zoning prohibits the use of property for specific purposes, and sanitary regulations have to do with public health, related pollution, and pest control.

Other restrictions that may limit the use of property include deed restrictions, easements, and covenants between property owners. Neighbors may become concerned about nuisances, whether there are specific regulations or not. So, check neighbors' reactions (and anticipate future neighbors' reactions) to your stabling of horses—especially if you live in an urbanized or developing area; ownership of urbanized property can change rapidly.

SITE SELECTION

The building site should be well drained, accessible, and have a slope of about 5'/100' away from the building in all directions to assure good surface drainage. Consider the grading and filling that will be needed for a well-drained site; plan on using only clean soil, sand, gravel, or crushed rock for fill.

Topography of the site, particularly, affects the cost of site development, and site preparation should be completed before building construction is started. A nearly level site usually involves the least cost. Sites on steep slopes or rocky terrain, or sites requiring considerable fill, are costly to develop and may make compromises necessary.

Among factors influencing selection of a building site are:

- **Size of operation**—In addition to room for the planned buildings, the site should provide space for other planned facilities and areas. It should also provide for future building and paddock expansion, and for good traffic patterns for safe and convenient handling of animals, vehicles, equipment, materials, and snow removal.

• **Restrictions**—The zoning regulations, building codes, sanitary regulations, deed restrictions, easements, and covenants mentioned earlier may affect or limit the development and use of property at a specific location.

• **Topography**—Surface characteristics of the land (such as direction and steepness of slope, gulleys, ravines, streams, swamps, knolls, hills, and rocks) affect site selection, development, convenience, and use. Boulders and rock outcrops or formations near the surface indicate that costly rock excavation may be required to develop the site and to install foundations and water and drainage lines.

Avoid sites that have serious drainage problems (such as steep slopes that concentrate surface runoff in the building area and wet areas caused by critical ground-water conditions) unless the problems can be completely eliminated. Avoid sites near streams that flood, and stay well above the highest flooding.

• **Water supply**—An adequate all-year water supply of the quality needed must be available at the site, either from a public water system or from convenient ground-water and surface water developments.

• **Nuisances**—Distracting noise, offensive odors, and heavy traffic may affect site selection. Consider existing nuisances that may affect you and your use and enjoyment of the site and also ones that you may create that might affect neighbors.

• **Windbreaks**—The natural protection from the elements provided by wooded areas, knolls, hills, and ravines is a consideration in site selection.

• **Existing buildings**—Existing buildings may be a determining factor in site selection, but only if their size, location, physical condition, and inside arrangement fit into the over-all plan for housing facilities.

• **Services**—The availability of electric service is essential.

• **Economy and aesthetics**—Appearance, personal taste, pride of ownership, and available funds may affect decisions in site selection.

• **Building layout**—Chances are that building layout will be a deciding factor in selecting the site, but the site chosen may affect both building layout and building style.

HOUSING

The horse barn, large or small, should be well planned, durable, and attractive. Its basic purpose is to provide an environment that protects the horses from temperature extremes, keeps them dry and out of the wind, eliminates drafts through the stables, provides fresh air in both winter and summer, and protects them from injury.

In cold uninsulated or insulated barns, fresh air usually is provided by natural air movement through wall openings and ridge ventilators. Wall openings may be small windows, wall panels, or slots under the eaves. In tight, warm barns, insulation, fans, and spaced air inlets are necessary. In cold climates, supplemental heat may be needed.

Provide ample space in the barn, based on established space requirements, for the well-being

of the animals, the convenience and safety of the people caring for them, and the enjoyment of the rider.

Stables and other facilities have features peculiar to their functions. These features are incorporated in two basic building shells: open-front buildings for minimal shelter, and completely enclosed buildings for optimum shelter. The usable space in open-front or enclosed basic shells may be confined only to the ground-floor level. Depending on wall height and roof design, however, additional space overhead for hay, bedding, and feed storage may be provided in both open-front and enclosed buildings in a mow or partial loft.

SPACE REQUIREMENTS

The Tables below list dimensions for basic facilities.

to 80 sq ft/1000 lb of animals housed.

Minimum ceiling height is 8' for a horse, 12' for horse and rider.

Table 425-1. Door dimensions.

	width x height
Stalls	4' x 8'
Small wheeled equipment	10' x 10'
Horse and rider	12' x 12'
Large equipment, horse + rider	16' x 14'

Table 425-2. Hay manger and grain box dimensions (dimensioning inside the stall).

	Hay Manger ¹	Dimensions	Grain Box
All Mature Animals (Mares, Geldings, Brood Mares, Stallions)	30" - 36" 38" - 42" 20" - 24" 24" - 30"	Length Throat Height Width Depth	20" - 24" 38" - 42" 12" - 16" 8" - 12"
Foals and 2-year olds	24" - 30" 32" - 36" 16" - 20" 20" - 24"	Length Throat Height Width Depth	16" - 20" 32" - 36" 10" - 16" 6" - 8"
Ponies	24" 32" 18" 20"	Length Throat Height Width Depth	18" 32" 10" 6" - 8"

¹Wall corner hay racks are often used instead of mangers. Five feet is the usual distance between the floor and bottom of the rack. Many horsemen feed hay on the stall floor in both box and tie stalls and use a wall-mounted grain box in the corner of the stall.

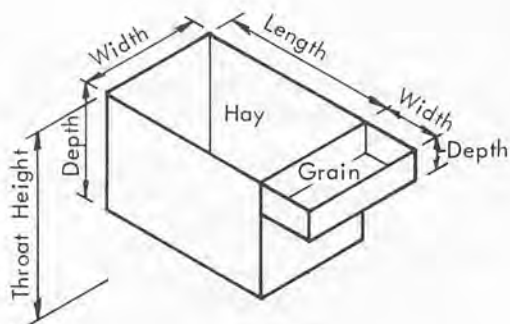


Table 425-3. Space requirements for horses in buildings.

	Dimensions of Stalls including Manger	
	Box Stall Size	Tie Stall Size
Mature Animal (Mare or Gelding)	10' x 10' small	
	10' x 12' medium	 5' x 9'
	12' x 12' large	 5' x 12'
Brood Mare	12' x 12' or larger	
Foal to 2-year old	10' x 10' average	 4½' x 9'
	12' x 12' large	 5' x 9'
Stallion ¹	14' x 14' or larger	
Pony	9' x 9' average	 3' x 6'

¹Work stallions daily or provide a 2-4 acre paddock for exercise.

OPEN-FRONT BUILDINGS

When horses are kept outside, provide free-choice shelter. An open-front shed will usually provide adequate protection. If a large building is needed, provide a building at least 32' wide for moderate climates and 40' wide for cold climates, and large enough to provide 60 to 80 sq ft of floor space per 1000 lb of animal weight using the shelter. Additional room may be needed in the shelter for hay and bedding storage, foal creep, pens, etc.

Face the open side of the building, like the open side of any other livestock shelter, away from prevailing winds. The desirable clearance on the open side is 10'. Although hay and bedding storage may be in the shelter, feed hay outside the building in racks to conserve bedding. Provide an adequate supply of fresh clean water. This may require a heated stock waterer for winter use. A single heated water bowl will serve 8 to 10 horses.

When selecting a site for the shelter, consider its location in relation to headquarters buildings and traffic lanes for the convenience of handling animals and servicing the facilities. Some artificial light is desirable. Provide 100 watts of light per 500 sq ft of floor area. Install ridge devices, and adjustable panels in the back wall, for summer and winter ventilation.

BARN LAYOUTS

Barn layouts are associated with both function and engineering design. Barns classified by function or use are: breeding, riding, loose housing, hay, and utility.

Barn Width

Determine the proper barn width during the planning stages. Match the functional requirements of the building with the attainable wants of the owner to determine the width (and length) of a structure. The outside dimensions of the structure should allow for all of the planned inside arrangements and facilities without compromising on size.

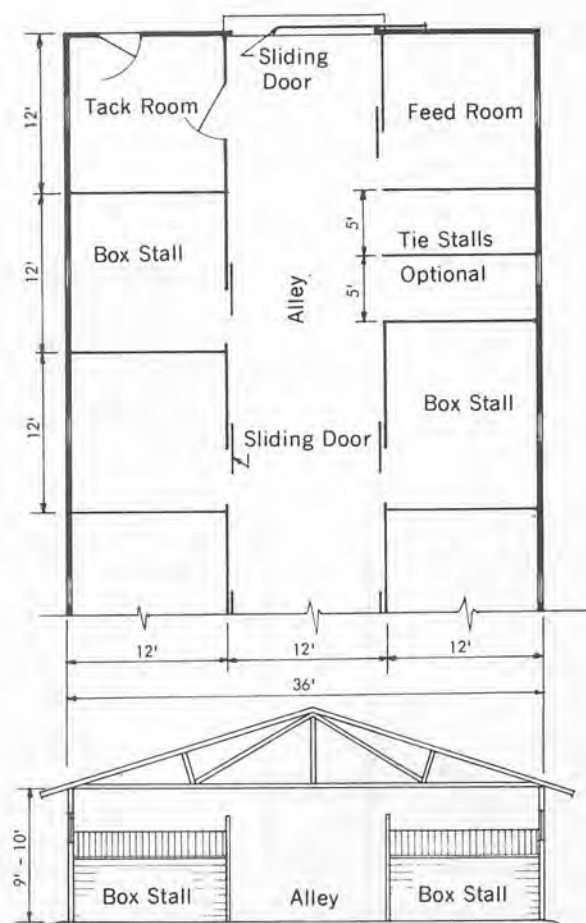
Outside dimensions of buildings always indicate the outside size of the finished structure. Some space in most buildings is taken up by walls and other structural members, reducing the usable space

inside the building. This reduction may result in less space and smaller facilities than those actually needed, especially if planning decisions were based on minimum space requirements, and the space-consuming structural features of the building were ignored. Two rows of 10'x10' box stalls separated by a 10' wide alley will not fit into a building having a 30' outside dimension; but, they will fit nicely with very little room to spare in one that has a 32' outside dimension.

Minimum space requirements cannot be reduced when the welfare of the animal and the performance of associated activities are considered. However, reference to minimum dimensions does not preclude more expansive facilities. Many horse owners consider minimum dimensions and space requirements undersized and incompatible with adequate housing, horse care, riding enjoyment, convenience, and the efficient use of labor.

Layouts For Box Stalls

The width of a structure for box stalls is determined by stall size and alley width. Typical building widths (outside measurement) for enclosed structures and for various box stall arrangements are illustrated. The most often used width increment is 12'. Clear distances inside stalls and alleys will then be about 11'-11"-6". Select actual sizes to meet your needs.

**Fig 425-1. Two rows of stalls, center alley (inside service).**

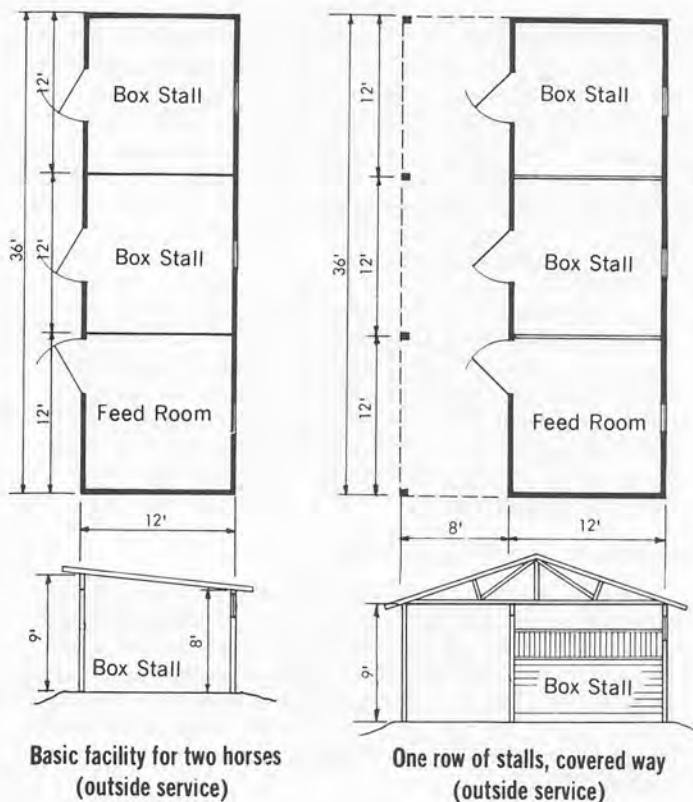


Fig 425-2. Small barns with box stalls.

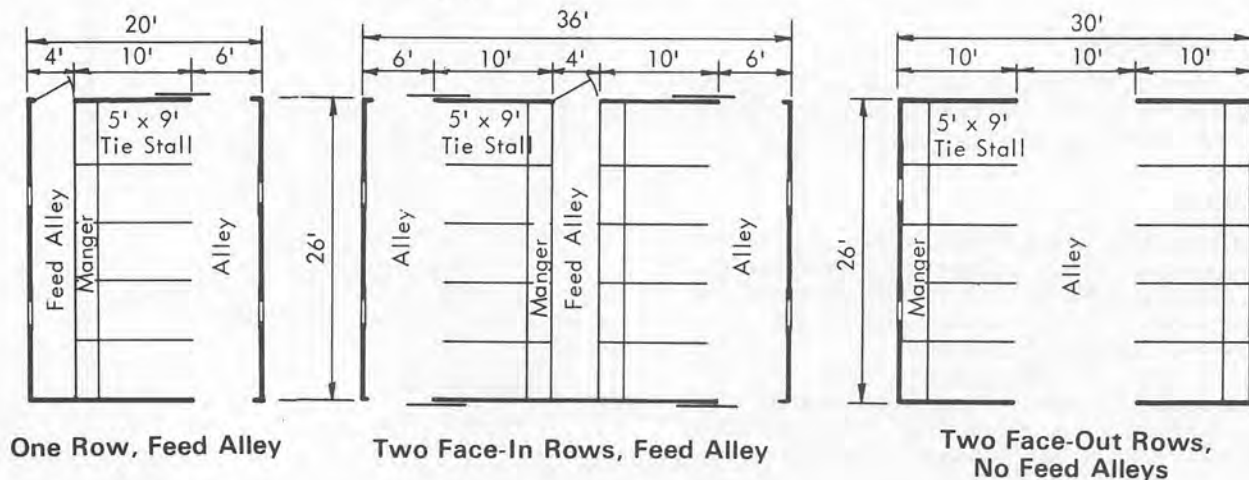
Layouts For Other Horse Facilities Are Variable

The important thing is to have enough clear width (as well as ceiling height and building length) for the activities associated with the structure. Activities involving strenuous exercise are limited to wide clear-span structures or outside arenas. The various covered facilities and their widths based on use are:

- Alleys separating two rows of stalls in box stall barns are used for handling and resting animals, and for limited exercise and training. The alley may be as narrow as 10' in barns 32' wide, and as wide as 28' in barns 50' wide.
- Basic clear span structures 36'-50' wide are used for exercising and training horses and as sales barns. Riding is limited.
- Basic clear span structures 50'-100' wide are used as exercise, training, and riding arenas. Widths of less than 60', though usable for riding, are not as desirable as widths of 60' or more. Widths of 80' or more are considered spacious. A clear span width of 110' is recommended for an indoor show ring.
- Roofed, open-front housing structure widths are variable. A width of 32' is considered minimal for animal shelters, storage and utility buildings. Clear span structures are usually more desirable than post and beam construction.

Fig 425-3. Layouts with tie stalls.

The width of a structure for tie stalls is determined by stall length and alley width. If the building has both box stalls and tie stalls, the size of the box stalls usually determines barn width.



BARN CONSTRUCTION

Ceiling Height

The minimum distance from the floor to the under side of floor joists in a two-story barn, or to the under side of the lower chord of trusses or rafters in a one-story barn, should be 8' for the horse only, and 12' for the horse and rider. Low ceilings interfere with ventilation, make the barn dark, and are a safety hazard for man and horse.

Commonly used ceiling heights for stall barns are 9'-10' and for riding areas 14'-16'.

Alleys

For convenience, safety, and animal traffic, provide 10' or wider litter and work alleys between stalls. This allows room for moving horses, a small truck, or a tractor pulling a wagon or a manure spreader.

Provide at least a 6' litter alley when it is back of a single row of stalls. More hand labor is required to clean narrow alleys; also, moving horses through them is more difficult.

Use a 4' minimum width for feed alleys for convenient feeding, especially with baled hay. Cross alleys are also 4'. The paving of alleys is optional.

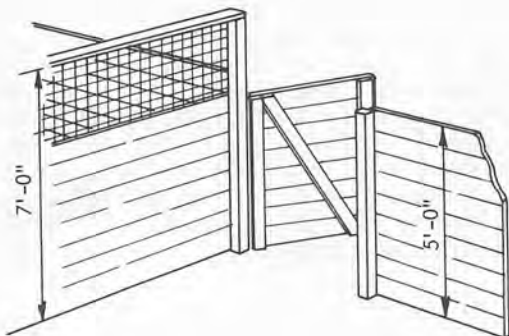
Doors at the ends of litter alleys are either sliding or overhead type and should be sized for the kind of traffic using them.

Stalls

Table 425-4. Characteristics of stalls.

Item	Tie Stalls	Box Stalls
Water	out-of-stall	in-stall
Feed	in-stall	in-stall
Manure	less carrying	more carrying
Bedding	less required	more required
Exercise	out-of-stall	limited in-stall
Space	45 to 60 sq ft	100 to 320 sq ft
Floor	clay or plank	clay or plank
Partitions	strong & tight	strong & tight
Top Guard	manger end	on partitions

The upper portion (2'-2½') of the stall partition is often a rugged open panel or guard. This more-or-less open section aids ventilation and makes observation possible. The alley wall may be 5½' high with no guard.



Various materials are used for the open guard, such as: vertical ½" diameter steel rods, or ¾" pipe spaced not more than 4" on center; sections of #4 gage welded steel fence; flattened 1½", 9 gage expanded steel mesh; #6 gage welded wire 4" x 4" mesh; chain link fencing; vertical wood slats.

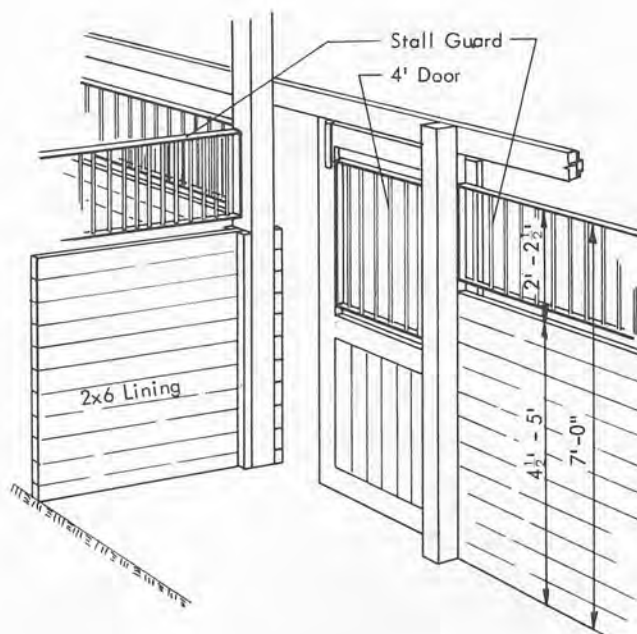
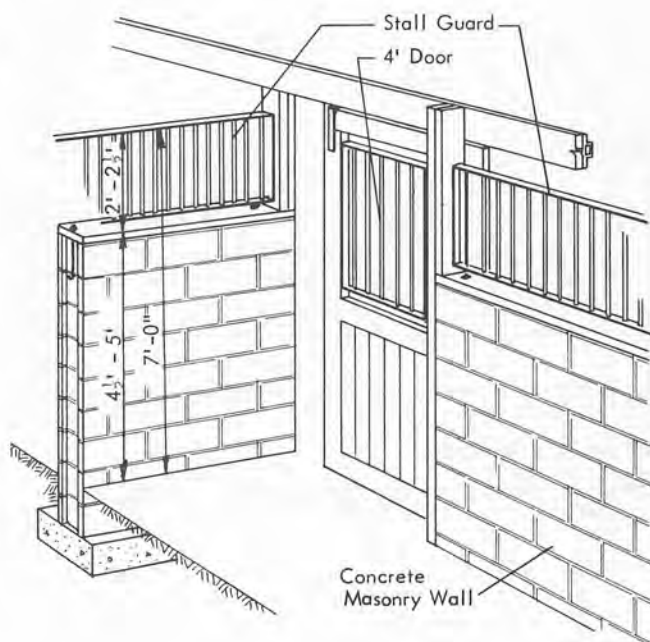


Fig 425-4. Typical box stall construction and arrangements.

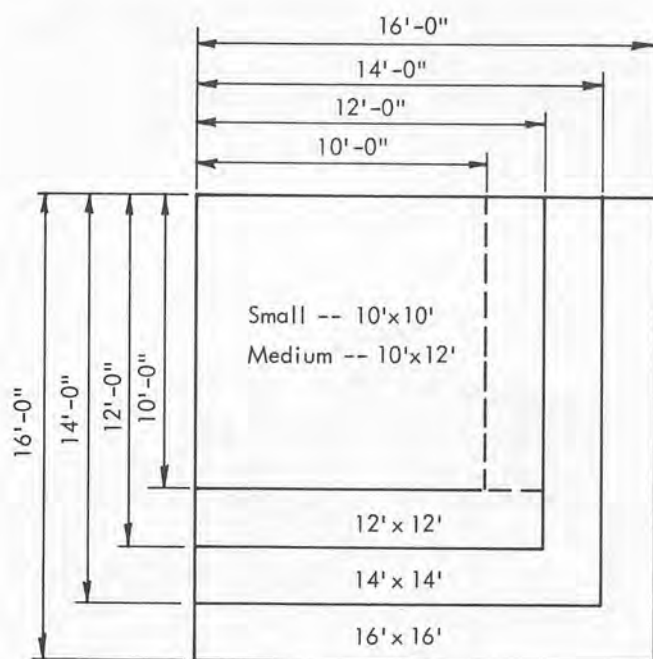


Fig 425-5. Box stall sizes.

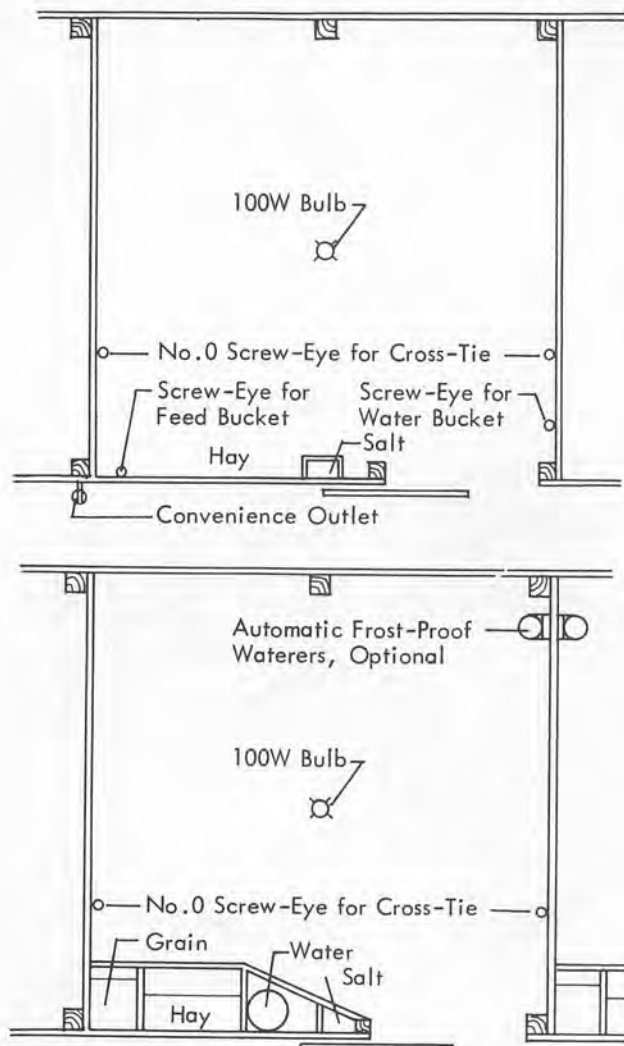


Fig 425-6. Typical box stall layouts.

Many barns have only box stalls; but seldom does a barn have only tie stalls. In most horse barns some box stall space is necessary for sick animals, mares at foaling time, and colts.

Use stall walls that are tight, smooth, and free of sharp corners, loose wires, protruding bolts and nails, and anything else that might injure the horse as it moves about and lies down. The walls must be flush with the floor, so a horse cannot get its feet under the partition.

Wood is the most common material for stalls—commonly 2" hardwood planks to withstand rough treatment, chewing, and kicking. Concrete masonry walls are widely used in areas where climatic conditions can be controlled by waterproofing the outside stall walls and filling the block with insulation material to reduce heat loss. Block are smooth and withstand rough treatment, and chewing by the horses is no problem. Concrete masonry partitions in horse barns are becoming more common.

Box stalls

For riding horses, the minimum box stall is 10' x 10'. More commonly, box stalls are 12' x 12', although stalls 16' x 16' or larger are not uncommon. If the barn layout permits, a stall 16' x 20' or larger is useful for foaling mares. Box stalls for ponies may be smaller, depending on breed. A large stall can be obtained by removing the common partition between adjoining box stalls.

Equip box stalls with rugged Dutch doors, a full length sliding door, or swinging gates hung with heavy hardware. Horses can open doors, so to be safe, install door fasteners that the attendant can operate from inside and outside the stall and that the horse cannot open. A stay roller or guide is required outside the bottom of sliding doors to hold them in place.

Provide a convenient and safe stall arrangement. Consider both the attendant and the horse. Include provisions for watering; feeding hay, grain, salt and minerals; and for cross-tying the animals.

Either built-in hay-grain box combination mangers similar to those used in tie stalls, or individual wall-mounted hay racks and grain boxes, are used in box stalls. Or, hay may be fed on the stall floor.

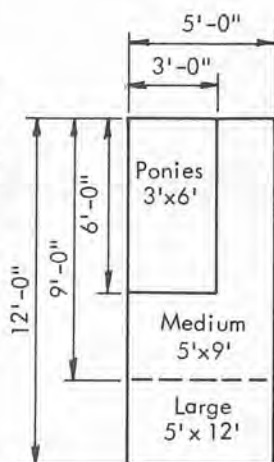
The stall corner supports are usually pressure-treated posts or poles; steel pipe up to 5" in diameter is also used. In post and beam construction, the posts or poles serve as anchors for the end of the stall partitions, and their size is based on roof and mow design. All wood in contact with the ground or foundation should be pressure-treated.

Box stalls are preferred to tie stalls for pleasure horses. Use 7' high box stall partitions to prevent fighting. The lower 4½'-5' of the 7' stall partitions and inside walls are usually made tight in cold climates, to prevent drafts and to protect the animals. Partition boards, spaced not more than 1½" apart, allow better ventilation but may require vertical center bracing to keep the wall true. Concrete masonry partitions are popular because of ease of construction, durability, and low maintenance.

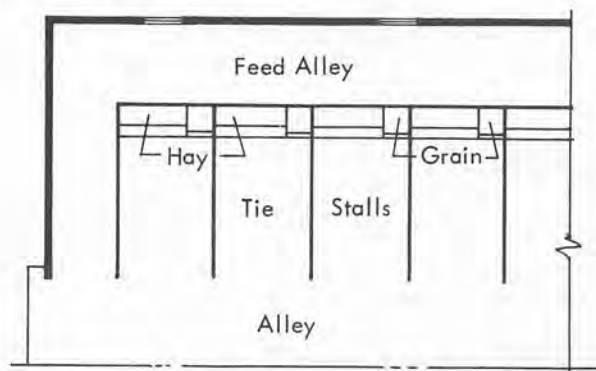
Tie Stalls

Fig 425-7. Tie stall dimensions.

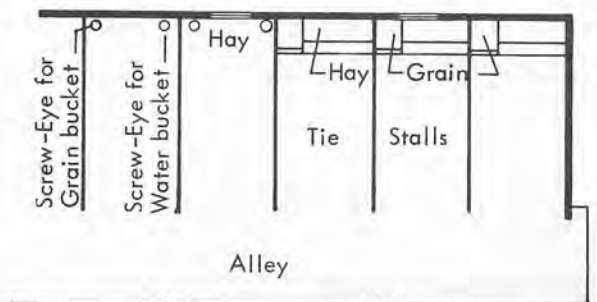
Tie stalls are not as widely used for pleasure horses as box stalls. However, they do provide an area for confining animals that are restless in box stalls. Tie stalls require about half the area, less bedding, and are easier to clean than box stalls. They can often be constructed in existing buildings unsuitable for box stalls.



The typical tie stall is 5' x 9' (3' x 6' for ponies), although stall lengths up to 12' are often used. The length of the stall is measured from the front of the manger or grain box to the rear of the stall partition. The top of a wood built-in manger is about 2' wide. The standing platform is 7' long or longer. The built-in manger slopes forward at the bottom on the standing platform side to protect the stabled animals' knees. Individual grain boxes and hay racks are sometimes used in tie stalls instead of built-in wood mangers. Hay is occasionally fed on the floor. Horses are usually removed from the stalls for water and exercise, although watering in the stall is not uncommon.



Tie Stalls facing out - serviced from front feed alley - Built-In Manger



Tie Stalls along wall - serviced from the rear Built-In Mangers & Minimum stall equipment shown.

A litter alley at least 6' wide and with a gutter is required behind a single row of tie stalls. A 10'-12' litter alley with gutters separates two rows of stalls facing out. A 3½'-4' feed alley in front of each row of stalls is desirable. But, feeding can be handled satisfactorily from the rear of a stall not serviced by a front feed alley.

Provide partitions between tie stalls high enough at the manger end to keep the animals from fighting. Use a height of at least 6' for the front or manger end of the partition, and 4½' at the rear.

The amount of bedding needed depends upon the type of floor, type of stable, and the weather. Provide 8 to 15 lbs of bedding per day per 1000 lb animal weight in occupied stalls. Always keep the bedding clean and well fluffed up. Never leave it hard or lumpy.

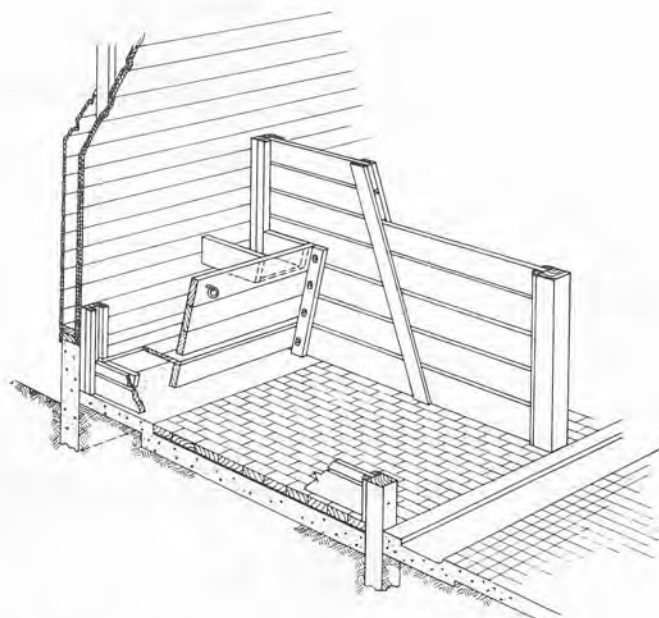
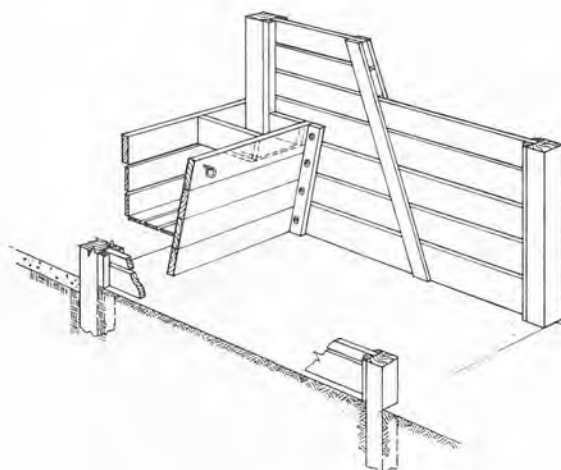
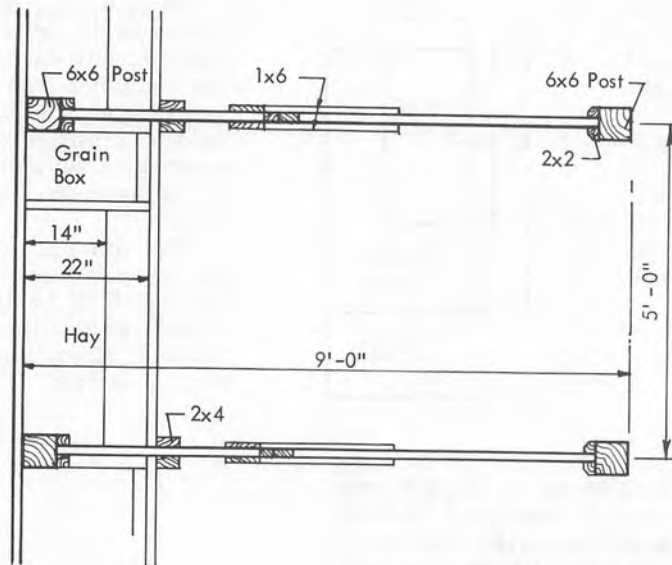


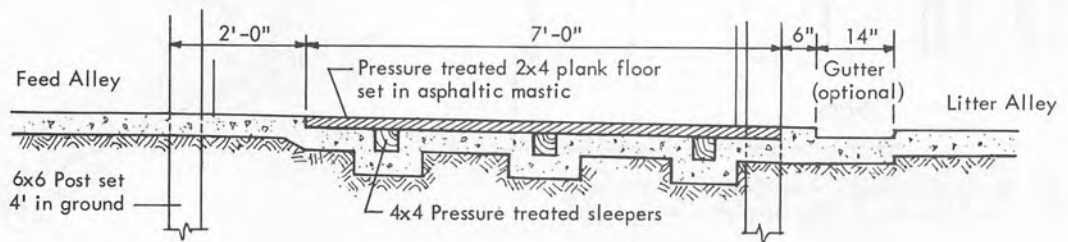
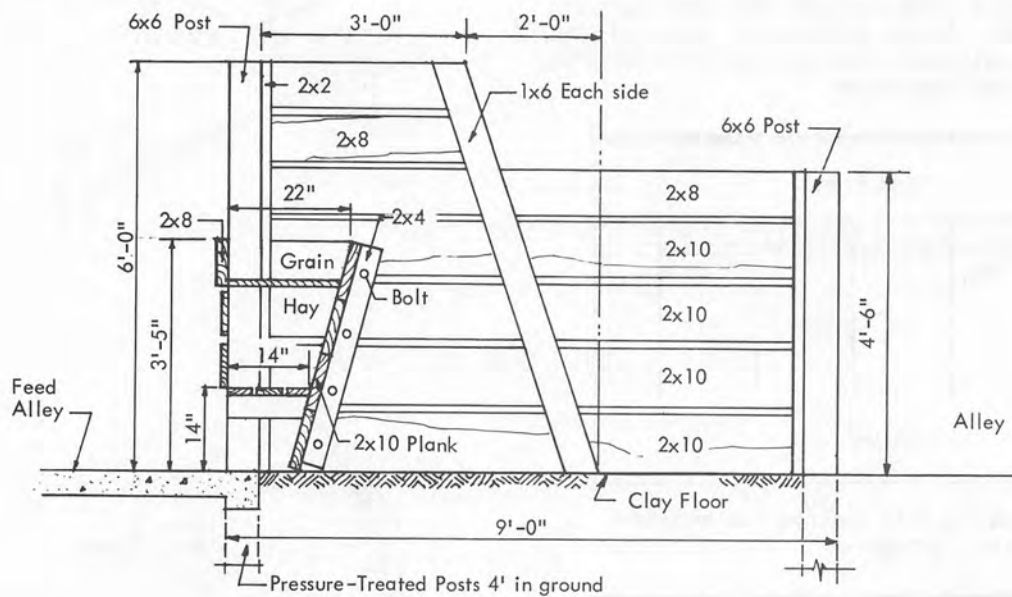
Fig 425-9. Tie stalls.

Fig 425-8. Typical tie stall arrangements.

Fig 425-10. Tie stall details.



Floor Plan



Alternate Floor

Feed Room

Organize the feed room, which is seldom larger than the size of a box stall, for convenience and easy housekeeping. Plan storage for feed materials, equipment, and tools. Provide an uncluttered traffic pattern to reach the stored materials without interference. Keep the storage area as dust free as possible.

Hay may be stored in an overhead loft or on the ground floor. Small rooms and narrow doors are inconvenient for storing hay and add to the chore labor required to handle it, both in and out of storage.

Grain feed must be stored in vermin-proof bins or containers. Metal containers such as large garbage cans and wood bins with tight lids are excellent for limited bulk feed storage. Hopper-bottom bins with mechanical unloading are also used either inside or outside the barn. Homemade and commercial grain bins are used for storing grain in large quantities.

The feed room should be well lighted, and equipped with convenience outlets. Provide 150 watts of light and at least two convenience outlets in the feed room. The entrance door to the feed room should be at least 4' wide and equipped with a latch so that a loose horse cannot get into the feed. A good rodent-control program is essential.

Provide space for feed storage on a rule-of-thumb basis: $1\frac{1}{4}$ lb of hay and 1 lb of grain per day per 100 lb of the horses' weight. Baled hay will weigh approximately 10 lb/cu ft, and a ton will occupy approximately 200 cu ft. Whole oats weigh approximately 26 lb/cu ft (80 cu ft/ton); ear corn about 28 lb/cu ft (70 cu ft/ton); and bulk feed about 40 lb/cu ft (50 cu ft/ton).

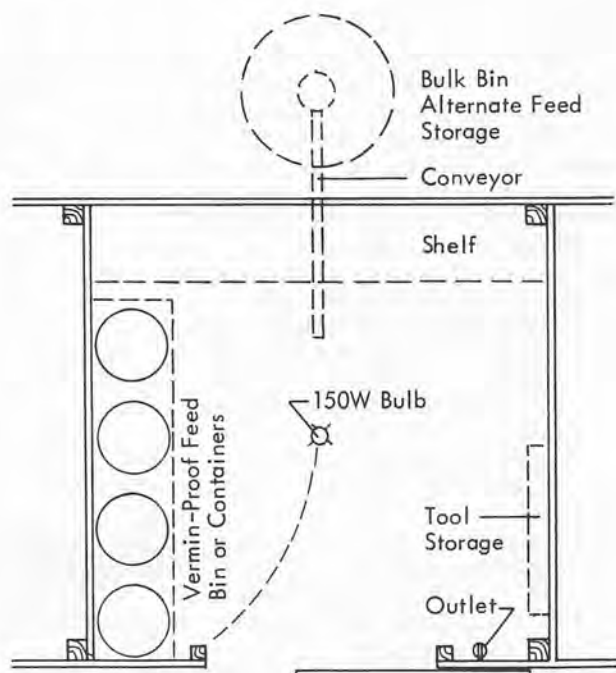


Fig 425-10. Typical feed room.

The amount of storage space needed will depend on the number of animals, their total weight, and how often the feed supply is to be replenished.

Tack Room

A well organized and maintained tack room that is enclosed, dry, and free of dust is important to good stable management. In smaller stables it is simply an equipment storage area. In larger stables the tack room has traditionally been the horseman's headquarters for essential equipment and activities associated with horse owners. It can be simply a small area or room for riding equipment, or it can be large enough to serve as an office, a service shop for cleaning and maintaining tack, and a meeting and lounging place for the clan.

Build the tack room large enough for the activities associated with it. The tack room may contain all or some of the following equipment and facilities: saddle racks, tack box, bridle and halter racks, shoeing box, first aid kit, clothes closet, storage cabinets, shelves, filing cabinets, desk, chairs, miscellaneous furniture, refrigerators, sink, working and loafing areas, heating equipment, hot and cold running water, and cooking facilities. Toilet and shower facilities may be adjacent.

Install at least 300 watts of incandescent lighting (100 watts fluorescent) per 100 sq ft of floor area and provide adequate convenience outlets.

The tack room provides a warm area in the barn when insulated and heated for winter use. Side wall and ceiling insulation 2" thick plus electric heat and ventilation economically keep the area dry and comfortable in cold weather.

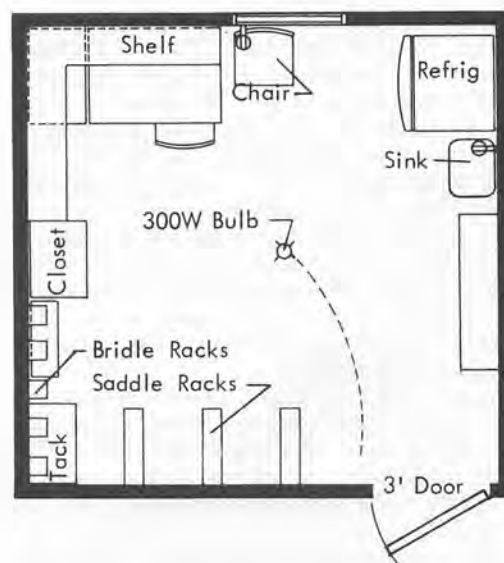


Fig 425-11. Typical tack room.

Floors

Packed or puddled rock-free clay on a well-drained base makes one of the best floors for stables. It is usually easy to obtain. However, it is difficult to keep clean and has to be renewed from time to time. Wood plank stall floors or wood block floors on concrete are preferred by some horse owners, but such floors are very difficult to keep dry and free of odors. Concrete floors are the least desirable, and if used, a considerable amount of bedding, such as sawdust, is needed to prevent stiffness. Artificial turf (tartan) is used for stall floors and alleys by some innovators.

To ensure adequate drainage, elevate the top of the floor 8"-12" above the outside ground level. Concrete floors are used in the wash area and are desirable in the feed room, feed alleys, and tack room. Avoid floor finishes that are too slick, such as troweled concrete and some asphalts. Examples of floor construction are shown in the tie stall construction details.

Mangers and Racks for Hay and Grain

Construct mangers and grain boxes from 2" hardwood or equivalent material using the dimensions in Table 425-2. Corner or wall hay racks may be used instead of built-in wood mangers. Corner hay racks extend approximately 2' each way from the corner of the stall and usually have a circular front. Wall hay racks are approximately 4' wide with straight or circular fronts. All mangers should be constructed so they are convenient for horses to eat from and convenient for attendants to service.

Separate grain boxes, usually located in a stall corner for convenient feeding, are used in both box and tie stalls, especially when hay is fed in wall racks or on the stable floor. Grain boxes in box stalls are usually filled through a small opening in the front wall, and in tie stalls from the rear of the stall or from a front feed alley.

Windows

A small adjustable 2' x 2' window in each box stall will provide light and assist in ventilation. However, windows are not essential if other methods are used for lighting and ventilating the building. Locate windows near the top of the wall. Allow at least 6' between the window sill and the stall floor. Protect all windows that can be reached by horses with heavy 1" x 2" welded wire or a steel grating. Attach the protective guard to the window so it can be easily removed for window cleaning.

Translucent roof and wall panels are used to admit daylight into some animal shelters. However, they may become a heat source in the summer and are subject to severe moisture conditions and frosting in cold weather.

Windows add to building costs. Summer ventilation can be provided by solid adjustable ventilation doors near the top of outside walls instead of, or in addition to, windows. Jalousie-type windows are widely used in horse barns—they admit air and light, exclude rain, are easily adjusted, and window guards do not interfere with their operation.

Lighting

Good illumination is important for the convenience and safety of both the horse and the attendant. Provide lighting for:

- General illumination of alleys and pathways.
- Specific illumination of stalls, storage areas, and specialty areas.
- Outside approach and service areas.

For stall lighting, place one 100 watt bulb near the center of each stall if height permits (9' or higher); locate switches near the stalls. Foaling stalls need about 300 watts of light.

Recess lights into the ceiling or use guards so the animals cannot break the bulb and fixture. Dust-free fixtures are desirable. Reflectors will improve lighting in stalls, alleys, and walk areas. Locate convenience outlets for the use of portable lights and equipment in alleys, tack room, and storage areas.

Locate general illumination at exterior doors.

Control outside lights from a switch near the barn entrance, or 3- or 4-way switches to allow control from both the barn and the residence.

Electric wiring and fixtures must comply with applicable state and national electric codes.

Water

A healthy horse needs an adequate supply of fresh water of the same quality as is used for human consumption. A mature horse needs 8 to 12 gallons per day.

The vast majority of horses are hand watered. Locate in-stall watering devices where spillage can drain directly from the stall—they may need filling more than once a day in a cold barn because of freezing. A stop and drain (frostproof) hydrant or an electrically heated watering bowl will supply fresh water in freezing weather. One electrically heated watering unit can serve two stalls or serve 8 to 10 horses in a lot.

MANURE HANDLING

Manure management is an important part of caring for horses. The physical and social aspects of collecting, handling, storing, transporting, and disposing of manure are a major problem. Problems occur when collection, storage, and disposal methods contaminate a water supply and are responsible for odors, flies, and other nuisances.

Check local regulations for storage and disposal recommendations. If regulations exist, follow them. In the absence of regulations:

- Dispose of manure daily when possible.
- Provide temporary storage for manure that cannot be disposed of daily—about 12 sq ft of fenced or enclosed storage per horse.
- Locate the storage in an approved or safe area for convenient removal, away from any water source and out of natural drainage channels.
- Empty the storage at least weekly during fly breeding season (spring temperatures above 65°F until the first killing frost in the fall).
- Drain the storage area away from surrounding facilities and lots.
- Keep all runoff that is polluted with animal waste from reaching usable or public waters by diverting it to a non-critical area or pond (lagoon).

Table 425-5. Light horse rations¹

Age, Sex and Use	Live Weight		Daily Allowance (lb per 100 lb live weight)		
	lb	kg	Grain	Hay	Ration Type ²
Stallions in breeding season	900-1400	408-635	3/4-1 1/2	3/4-1 1/2	1, 2, 3
Pregnant mares	900-1400	408-635	3/4-1 1/2	3/4-1 1/2	4, 5, 6
Foals before weaning	100-350	45-159	1/2-3/4	1/2-3/4	4, 7, 8
Weanlings	350-450	159-204	1-1 1/2	1 1/2-2	8, 9, 10
Yearlings	450-700	204-318	— Summer Pasture —		
in training	450-700	204-318	3/4-1 1/4	3/4-1 1/4	3, 4, 8, 10
Yearlings, or rising 2 year olds	700-1000	318-454	1/2-1	1-1 1/2	3, 4, 11
Light horses at work					
hard use	900-1400	408-635	1/4-1 1/2	1-1 1/4	3, 12, 13
medium use	900-1400	408-635	3/4-1	1-1 1/4	3, 12, 13
light use	900-1400	408-635	1/2	1-1 1/4	3, 12, 13
Mature idle horses	900-1400	408-635	—	1 1/2-1 3/4	—

¹From Light Horses, USDA Farmer's Bulletin 2127.²Refer to Table 425-6.Table 425-6. Grain rations for light horses¹.

Feed Material	lb of Feed Material per 100 lb of Ration												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Barley	—	—	—	—	45	—	—	30	—	—	35	—	30
Corn	—	35	—	—	—	—	—	—	—	—	—	70	—
Oats	55	35	100	80	45	95	50	30	70	80	35	30	70
Wheat	20	15	—	—	—	—	—	30	—	—	—	—	—
Wheat bran	20	15	—	20	10	—	40	—	15	—	15	—	—
Linseed meal	5	—	—	—	—	5	10	10	15	20	15	—	—

¹From Light Horses, USDA Farmer's Bulletin 2127.

Table 425-7. Water requirements.

Type and age of animal	Gallons per head per day
Mature (mare or gelding)	8-12
Brood mares	8-12
Foals to 2-yr olds	6- 8
Stallions	8-12
Ponies	6- 8

Bedding

Provide dry bedding that will adequately support the horse and keep it comfortable. Useful materials include peat moss, straw, shavings, sawdust, and old hay mixed with wood shavings.

Table 425-8. Bedding material approximate water-absorbing capacity.

lbs of water/lb of bedding	
4.0	Tanning bark
3.0	Pine chips
2.5	sawdust
2.0	shavings
1.0	needles
1.5	Hardwood chips, shavings or sawdust
2.5	Shredded stover
2.1	Ground cobs
2.8	Oats, threshed
2.5	combined
2.4	chopped
3.0	HAY, chopped mature

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CHAPTER 426 POULTRY

Table 426-1. Summary of environment recommendations.

AGE	FLOOR SPACE	FEEDERS	WATERERS	ROOSTS	
0-4 weeks (Brooder House)	1/2 sq. ft./chick.	1 in. per chick or one 4-ft. feeder per 100 chicks.	Three 1-gal. fountains or 40-in. trough per 100 chicks.	Spacing In.	Length In./bird
4-10 weeks (Brooder)	1 sq. ft./bird.	2 in. feeding space per bird.	Two 5-gal. waterers per 100 chicks.	8	4
10-20 weeks	2 sq. ft./bird (1/2 sq. ft. roost area/bird on range.)	4 in. feeding space/bird.	One 4-ft. automatic watering trough per 100 birds.	12	6
Maturity (Laying House)	1 1/4 sq. ft./bird, feed and water over pits. 2 1/2 sq. ft./bird feed or water over pits. 3 sq. ft./bird feed and water on the floor.	3-4 in. feeding space per bird. 1-4' oyster shell & 1-4' grit hopper/100 birds.	One 4-ft. automatic watering trough/100 birds, or 1 fountain/100-150 birds. (6 gal./day/100 birds.)	12 Very Hot Weather 15	7 8-10 (1/2 sq. ft. pit area/bird min.)
Broiler Hens	3 sq. ft./bird	4-6 in./bird.	Same as for layers.	15	8-10

Equipment

The edge of feeders and waterers should be level with the birds' backs. Birds should not have to walk more than 10' to feed, water, or nests. Let droppings accumulate. Clean for each new flock of layers.

Automatic waterers are economical even in small flocks. Automatic feeders should be used for flocks of 3000 birds or more.

Consider a stand-by generator for large flocks (a must for windowless houses).

Nests

Provide one nest, or equivalent for each 4-5 birds. Avoid obstructions between feed, water and nests.

Extra nests may reduce floor eggs. Use the same type of nests on the range as in the laying house.

Provide nests on range, or house the birds before the pullets start to lay. Nests 9" wide are adequate, except 11"-12" wide nests should be used for broiler hens.

Windows

Provide 0 to 5 sq ft of glass per 100 sq ft of floor area.

Hens have poor vertical vision, are stimulated by red light, and are blind to blue light. High light levels increase cannibalism. A blue light circuit can be provided for easier bird handling in broiler production.

Lighting

A 40-60w incandescent bulb is required for each 200 sq ft of floor area. To stimulate the birds leave the lights on 13-14 hours per day. Up to 125w (or 40w fluorescent) per 200 sq ft is used for additional lighting on separate circuits for observation.

Chicks require 15w per 200 sq ft, 24 hours per day until they are 3 weeks old, to prevent pile-ups.

In work areas or for observation, fluorescent lighting spaced 10' apart is preferred. Provide outdoor lighting and burglar alarms.

Environment

Debeak at 1 day and before birds are housed.

When birds are on range, maximum capacity should be 500 birds per acre. Shelter size is based on roost space (see table above).

Dropping pits or slatted floors will cover from 1/2-4/5 of the floor area of a confined poultry house.

Environment Recommendations

Brooders

Brooding temperature should start at 95°. Reduce the temperature 5° per week to 55°.

Dimensions for Poultry

SECTION 2—POULTRY

2.1 Many variables, both known and unknown, tend to complicate the accuracy of developing weight versus age curves for poultry. Much of the growth data has been collected as part of studies where growth was a measure of environmental influences. Thermal environment (temperature, humidity, air movement and radiant flux), light, plane of nutrition, brooding temperature, date of hatch, and management practices have demonstrated varying effects on growth rate. Therefore, the curves in Figs. 1-4 should be considered as representative growth curves.

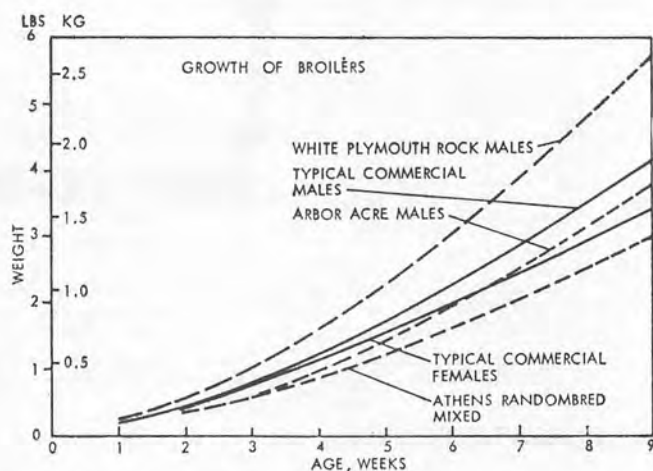


Fig 426-7. Weight versus age of broilers.

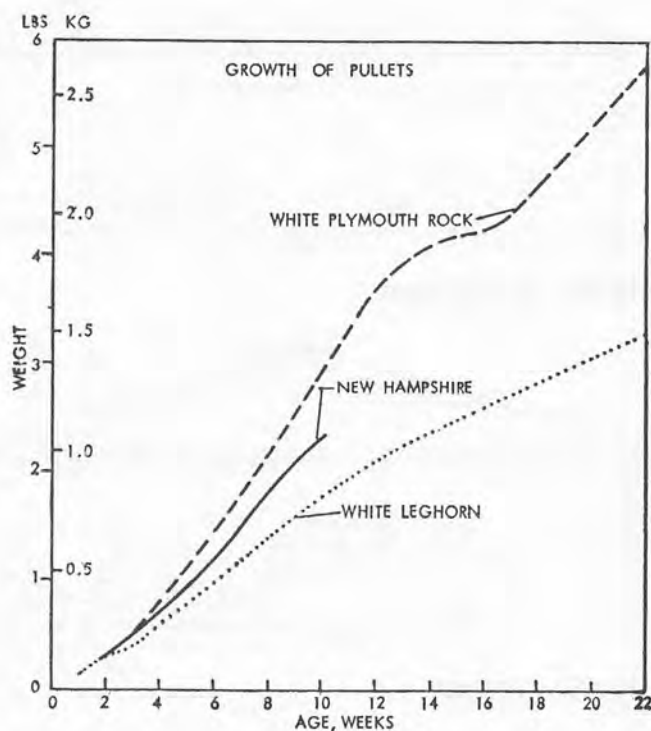


Fig 426-8. Weight versus age of pullets.

Table 426-3. Feed for chickens.

Live Weight		Total Feed Required per Bird per Year for Maintenance and Egg Production							
		0 Eggs per Year		100 Eggs per Year		200 Eggs per Year		300 Eggs per Year	
lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
3.0	1.4	47.5	21.5	61.5	27.9	75.0	34.0	89.0	40.4
3.5	1.6	52.0	23.6	67.0	30.4	80.5	36.5	95.0	43.1
4.0	1.8	56.5	25.6	72.0	32.7	85.0	38.6	99.0	44.9
4.5	2.0	61.0	27.7	75.0	34.0	89.0	40.4	103.0	46.7
5.0	2.3	65.0	29.5	79.0	35.8	93.5	42.4	108.0	49.0
5.5	2.5	69.5	31.5	83.5	37.9	98.0	44.5	112.0	50.8
6.0	2.7	74.0	33.6	88.0	39.9	102.5	46.5	115.0	52.2
6.5	2.9	78.5	35.6	92.5	41.9	105.5	47.8	120.0	54.4
7.0	3.2	81.5	37.0	96.0	43.5	110.0	49.9	124.0	56.2

Table 226-2. Water for poultry.

Age in Weeks or Condition	Daily Water Consumption Per 100 Birds	
	lb	kg
1- 3	5-15	2.3- 6.8
3- 6	10-25	4.5-11.3
6-10	25-35	11.3-15.9
9-13	30-40	13.6-18.1
Pullets	25-40	11.3-18.1
Non-laying hens	40	18.1
Laying hens (moderate temperature)	40-60	18.1-27.2
Laying hens (90 deg F temperature)	70	31.8
Growing Turkeys		
1- 3	65- 150	29.5- 68.0
4- 7	215- 490	97.5-222.3
9-13	500- 800	226.8-362.9
15-19	1000	453.6
21-26	850	385.6

TURKEYS

Breeders

Roosts should be 18" off the ground. Allow 12" of linear space per turkey for small breeds; and 16" per turkey for large breeds.

Space Confinement—When totally confining turkeys allow 10 sq ft per turkey; semi-confinement requires 12 sq ft per turkey; and range confinement requires 16 sq ft per turkey.

One waterer should be provided for every 100 birds. For small breeds, allow 10 linear feet per 100 birds. Large breeds require 12 linear feet per 100 birds.

One feeder is needed for every 100 birds. Small breeds require 40 linear feet per 100 birds; 50 linear feet for large breeds is sufficient or:

- 1—700 lb bulk feeder with 40" pan, or
- 4—hanging feeders with 16" pan.

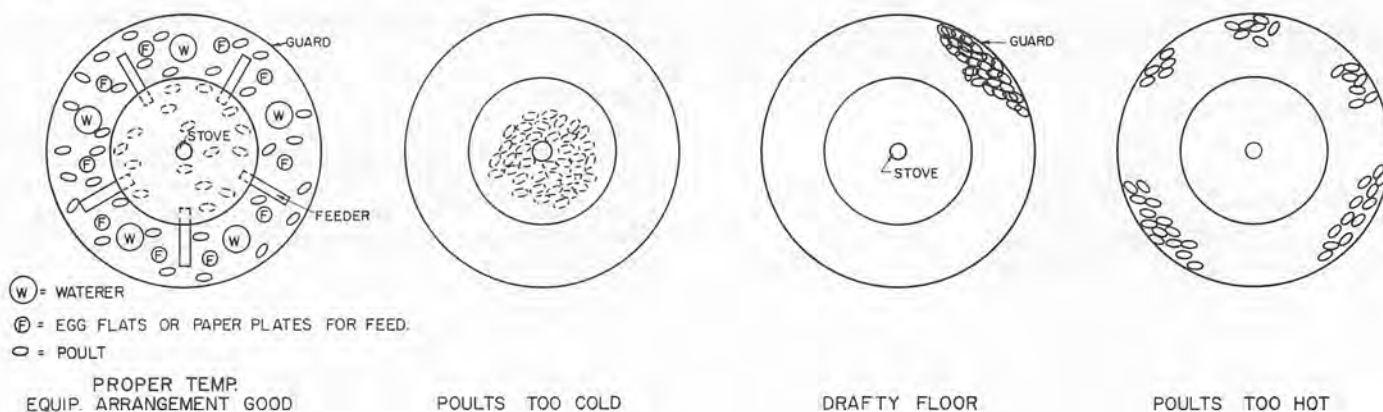


Fig 426-9. Feeder height recommendation.

One nest will serve 4-5 birds. For small breeds the nest should be at least 18" x 24" and for large breeds 24" x 24".

When natural mating is used, 10 toms per 100 hens is needed. Artificial insemination requires only 7 toms per 100 hens.

Fig 426-10. Poult or chick guide to hover temperature.



Hatching to 8 Weeks of Age

Debeak at 3-5 weeks—earlier if necessary to control cannibalism.

Allow 1 1/2 sq ft of floor space per poult. Each hover will provide space for 300 birds; or use 4 heat lamps per 150 poults. The temperature under each hover (3" from the floor) should be 95°F at the start. Reduce this temperature 5° per week until it reaches the natural air temperature of the building.

Feeder space per poult—2 linear inches of space for the first 4 weeks; 4" per poult after 4 weeks. Fill the feeders no more than half full after the first feeding.

Water space per poult—0.5 linear inches (35 poults per 1-gallon fountain at the start.

8 Weeks to Market

Range space—1,000 birds per acre. Move the birds to a new location each week. Total space required for confinement per 100 birds depends upon soil, crop, and climate. For small breeds:

Hens—3 sq ft per bird

Toms—5 sq ft per bird

For large breeds:

Hens—4 sq ft per bird

Toms—6 sq ft per bird

Feeder space per bird—5 linear inches per bird is required. Allow 1-1 1/2 linear inches per bird, or 2-4 automatic fountains per 100 birds.

Range shelters —Small breeds : 1.4 sq ft per bird

Large breeds : 1.8 sq ft per bird

Marketing age —Small breeds : 20-24 weeks

Large breeds : 24-28 weeks

Electric Fence

An adequate confinement fence can be made by placing 3/8" x 40" rod posts 16' o.c. Attach 2—#12 smooth wires 9" and 16" above the ground. Mowing or chemical weed control near the wires is required.

To keep birds out of feed and water troughs, place one live and one ground wire 1" apart over the trough.

RABBITS

Mating

Light breeds; 4-5 months old
Medium breeds; 6-7 months old
Giant breeds; 9-12 months old

The estrus cycle is 15 or 16 days, with conception possible with non-pregnant does at any time. One buck should be supplied for every 10 does. The gestation period lasts 31-32 days.

Kindle 2 or 3 litters per year for show animals, and 4 litters for commercial breeding. Some strains can be mated 6 weeks after kindling, and produce 5 litters per year.

Kindling

Provide a nest box in the hutch 27 days after mating. Does will pull fur to cover the litter. If they do not, pull fur from the doe and arrange the bed. (Litter may be kindled on hutch floor). The doe needs quiet a day or two before kindling and until restlessness stops after kindling.

Young Litters

On the day after kindling, carefully remove any dead or deformed young from the nest. Does can care for 6-8 young. Baby rabbits can be transferred to a foster mother. Mate several does to kindle at the same time.

Wean young from the does at 6-8 weeks. At this age the young will have started eating other feed.

Equipment

Individual hutches for mature rabbits should be up to 30" deep and 24" high. Waist-high, single-tier hutches are preferred. Wire floors require no bedding. Wire should be galvanized after welding, and any sharp points should be removed. In colder climates, close the back and ends. Solid or slat floors should slope to the back (rabbits will chew exposed wood).

Feeders

Crocks, troughs, hoppers, and hay mangers should be built to hold several feedings. A lip on the inside of these containers will prevent feed waste. Smaller units must be anchored. Use dividers to keep the young rabbits out of the trough. Use a separate space for each kind of feed or rabbits will scoop out less desirable feeds to eat other components first. Complete pellet feed is now common, which means no hay or hay rack need be provided.

Waterers

A half-gallon crock or coffee can securely anchored will serve as a waterer.

PIGEONS

Squab

A squab is a young pigeon, 12-24 ounces in weight that is marketed at 25-30 days of age.

Mating

Mate at 5-8 months of age. Pigeons usually mate for life and produce for 3-4 years. A pair will raise 10-14 squabs per year.

The hen lays one egg, skips a day, then lays another. The first egg will hatch in 17 days. The second, a day later. The hen often lays another pair 2-3 weeks later, therefore requiring 2 nests per pair.

Feeding

Feed minerals separate from the rest of the feed. Supply the pigeons with grit-washed gravel or granite chips. Feed cracked grain rather than mash. Both parents feed the squabs pigeon milk. Feed requirements for the parents are:

90-110 lbs of feed per pair per year

28 lbs per day per 100 pairs

7-8 lbs feed per lb dressed squab

Provide water in fountains for drinking, and in pans for bathing, or provide running water for both.

Fill self-feeders daily, or hand feed twice daily, an amount cleaned up in 1/2 hour. Keep pellets, if used, before the birds at all times.

Housing

Provide 3-4 sq ft of floor space per pair in pens of up to 30 pairs. Alternate solid and wire cross partitions. Alley partitions are made from wire, but are usually closed in winter.

Wood floors above grade, or concrete with 2" sand or gravel cover are satisfactory.

Use tight construction free of rodent harbors. Control rodents around pens and feed supplies with a continuous poison-bait program.

Winter lighting from 4:30 A.M. until daylight increases winter but not annual production.

Double nests should be 14" x 14" x 28", stacked 4-5 high with landing board and divider between nests. The dividers and landing board should be removable for cleaning. Close nest fronts for forced breeding. Provide 12 linear feet of feed trough space per 30 pairs. With self-dividers, allow 2" of space per pair. Wire mesh over feeders reduces waste.

Fly Pen

Use a 1" wire mesh enclosure. The wire should extend 12" into the ground vertically, and then run 12" horizontally for rat control. Use a sand or gravel floor, 3"-4" deep for drainage and easy cleaning. An 8" landing board near the top of the pen is desirable.

430 CROPS

CHAPTER 431—GRAIN-FEED CENTERS

INTRODUCTION

Knowledge of equipment and methods is an essential part of visualizing potential solutions to materials-handling and process-flow problems on the farm.

A Materials-Flow Concept

As the volume of crops produced and livestock fed increases through specialization and expansion, such things as timeliness, capacity to get the job done, quality control, and the dependability of purchased services become more important. As volume increases, so does mechanization. As volume increases, so does the importance of planning and organization.

One of the best keys to organizing farm mechanization is materials handling, or materials flow. This flow provides a logical basis for developing a system of handling a material; a means of integrating field machinery and farmstead equipment and structures; and a direction for growth and expansion. Effective "materials handling" is "organized materials flow."

Portable conveyors have moved much of the material in agriculture. A piece of equipment that could readily be moved to several locations used to be a real asset. Portability was sound with small volumes, low harvest and transport rates, and lots of labor. But these conditions are opposite to those on most farms today.

One piece of portable equipment can no longer do the whole job. There's an element of the "temporary" in a portable set-up. Today's processes require organized materials flow—ready-to-go equipment systems linked together to function as a unit.

The Need For Planning

Increased volume encourages larger structures. A more efficient, but more complex, materials-flow system encourages central permanent facilities. Such facilities require a minimum of knockdown and setup time between successive operations.

The progressive farmer today should be planning for, and leaving space for, a more complex process—for additional facilities, processes, and handling methods in the future. Tomorrow's volume may require a leg for handling, an automatic grinder-mixer, or a new type of dryer.

Someday, you'll be 10 years older handling twice the volume, and possibly 20 years more tired. What seems not worth considering today may be essential tomorrow. Leave room and think big—the structure will last at least 20 years.

The need for planning ahead can't be overemphasized. *Thousand-dollar decisions made without good planning may mean thousand-dollar mistakes.*

A good plan guides today's decisions and tomorrow's growth and expansion. Most farm plans cost two dollars or less—you need to get only one two-dollar idea. You can't afford to proceed without a plan.

Planning for the future primarily means leaving space for future facilities and equipment. Outline your best layout to fit your present and foreseen needs, *and then double it.* If this gives a completely ridiculous plan, revise the design to what you might do. But don't be too hasty to say the double scale is ridiculous—production has doubled on many farms in a few years. By doubling the "needed-soon" size, you consider potential extra volume. By building part of a large size plan, you can later add the next bin, an alternative dryer, a different handling method. It is easier and less costly to reach the expanded plan this way than to expand a facility to a size not considered in its original development.

CLOSED-LOOP HANDLING

The ideal grain-flow design develops a closed handling loop through each storage and process element. Grain is received in the drive-over grain dump, conveyed to the vertical elevator, and dropped by gravity to the bin. The bin is unloaded through an underfloor conveyor, which returns material to the drive-over dump. The loop is completed. Fig 431-1.

The grain bin in fig. 1 could be a bin-dryer without changing the flow. Or a high-temperature dryer might be added, developing a second handling loop that again returns grain to the starting point. Fig 431-2.

The drive-over grain dump and vertical elevator make the focal point or "center" of the layout; add storage elements around this central area. A four-bin layout with space for high-temperature drying might be as in Fig 431-3. The number of bins that can be fitted in obviously depends on the space and the driveway clearance.

The closed handling loops to this point have used gravity flow from the elevator. There are other ways of filling storages from a vertical elevator.

With bins on both sides of the center (driveway, dump, and vertical elevator), gravity flow may be used to one side, an overhead conveyor to the opposite side. The vertical leg is as close as possible to the gravity bin to reduce the elevator height needed. Fig 431-4.

Such a layout has a "wet" grain side and a "dry" grain side. If only some flow is by gravity, *use gravity flow for wet grain where possible.* Auger conveyors work much better on dry than on wet grain. Increasing the moisture content of corn in 6" augers from 14% to 25% requires 4 times the horsepower per bushel!

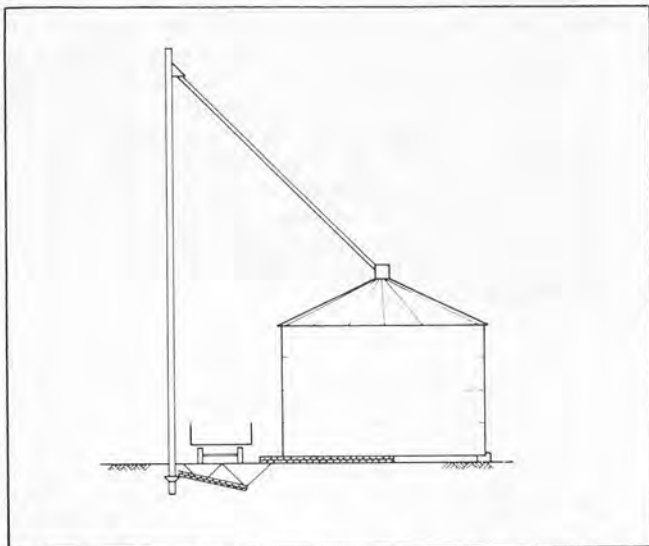


Fig 431-1. A simple closed handling loop—from dump to leg, spout, bin, unload auger, and back to dump.

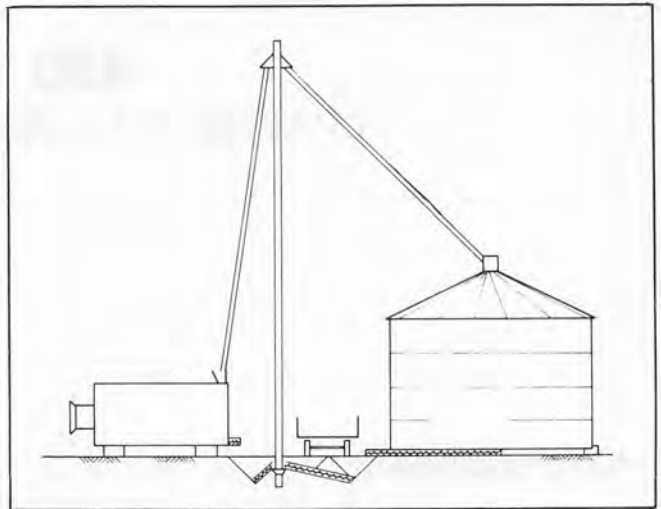


Fig 431-2. A second loop through a dryer.

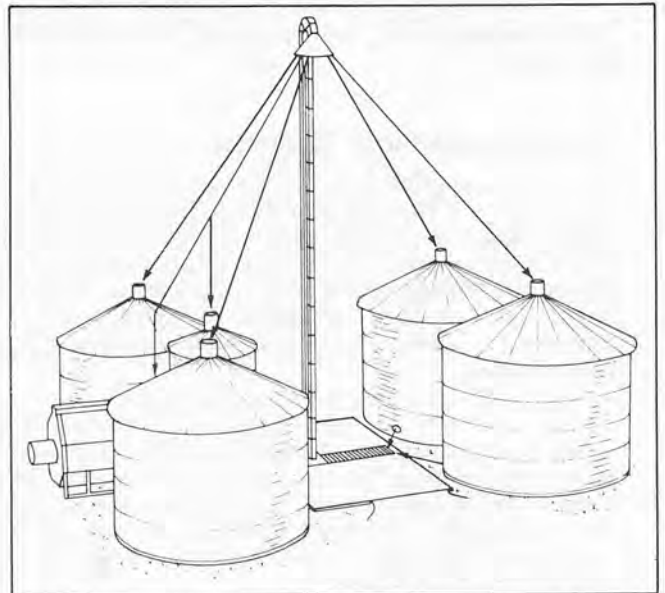


Fig 431-3. Several loops are built around the drive-over dump and vertical leg.

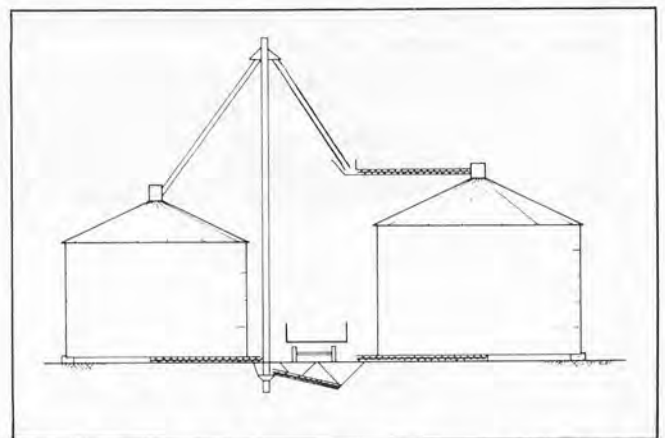


Fig 431-4. The leg can be close to the wet-grain side for gravity flow, with horizontal conveyors to the dry-grain side.

FARM-MATERIALS FLOW

The materials-flow process can be divided into its functions to identify some of the critical points and equipment alternatives. The functional sequence in grain harvesting/handling/drying is:

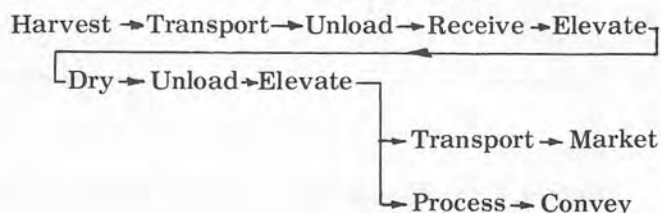


Table 431-1 lists the functions, with the equipment alternatives listed below them.

Select one method under each function. Connect them to arrive at a general design for a flow process; there are a number of alternative equipment systems to carry out each of the functions. The problems arise in deciding on the type of system to be used and in selecting component parts that will fit and operate together.

Table 431-1. Equipment alternatives for each flow function.

```

graph LR
    subgraph Harvesting
        H1[Picker mounted pull type]
        H2[Picker Sheller mounted pull type self propelled]
        H3[Combine pull type self propelled]
        H4[Broadcast vs row 1 to 8 row 20"-40" spacing]
    end

    subgraph Transport_Harvest
        T1[Wagon flat bed gravity bed feed wagon]
        T2[Truck straight pick up semi]
    end

    subgraph Unload_Harvest
        U1[Hydraulic Gravity]
        U2[Hoist, Wheel]
    end

    subgraph Receive_Harvest
        R1[Drive-Over Dump gravity auger chain oscillatory]
        R2[Drag hinged portable]
        R3[Hopper attached separate box, tire]
    end

    subgraph Elevate_Harvest
        E1[Inclined chain single double auger]
        E2[Vertical bucket belt chain auger blower]
    end

    subgraph Dry_Harvest
        D1[In-Bin layer batch]
        D2[Portable or Stationary batch manual automatic recirculating non-recirc. continuous flow horizontal tower]
    end

    H1 --> T1 --> U1 --> R1 --> E1 --> D1
    H2 --> T2 --> U2 --> R2 --> E2 --> D2
    H3 --> T2 --> U2 --> R3 --> E2 --> D2
    H4 --> T2 --> U2 --> R3 --> E2 --> D2

    D1 --> S1[STORE]
    D2 --> S1

    subgraph Store
        S1[Metal Bins round flat hopper]
        S2[Silos concrete steel]
        S3[Wood Buildings crib conv. others]
    end

    S1 --> U3[UNLOAD]
    S2 --> U3
    S3 --> U3

    subgraph Unload_Store
        U3[Sweeps Auger Chain Manual]
    end

    U3 --> E3[ELEVATE]

    subgraph Elevate_Store
        E3[Inclined chain single double auger]
        E4[Vertical bucket belt chain auger blower]
    end

    E3 --> CASH[CASH GRAIN]
    E4 --> CASH
    E3 --> LIVESTOCK[LIVESTOCK]
    E4 --> LIVESTOCK

    subgraph Cash_Transport
        C1[Truck straight pick up semi]
        C2[Wagon all types]
    end

    CASH --> C1
    CASH --> C2
    C1 -.-> MARKET[MARKET]
    C2 -.-> MARKET

    subgraph Livestock_Process
        L1[Blender-Grinder]
        L2[Grinder-Mixer stationary portable]
    end

    LIVESTOCK --> L1
    LIVESTOCK --> L2

    subgraph Convey_Livestock
        L3[Conveyor auger chain belt air]
        L4[Vehicle feed wagon truck wagon]
    end

    L1 --> L3
    L2 --> L3
    L3 --> L4
  
```

The flowchart illustrates the grain handling process, starting with Harvesting (Picker mounted pull type, Picker Sheller mounted pull type self propelled, Combine pull type self propelled, Broadcast vs row 1 to 8 row 20"-40" spacing) and Transport (Wagon flat bed gravity bed feed wagon, Truck straight pick up semi). The process continues through Unload (Hydraulic Gravity, Hoist, Wheel), Receive (Drive-Over Dump gravity auger chain oscillatory, Drag hinged portable, Hopper attached separate box, tire), Elevate (Inclined chain single double auger, Vertical bucket belt chain auger blower), and Dry (In-Bin layer batch, Portable or Stationary batch manual automatic recirculating non-recirc. continuous flow horizontal tower). The grain can then be STORED (Metal Bins round flat hopper, Silos concrete steel, Wood Buildings crib conv. others) or processed. Storage options include Metal Bins, Silos, and Wood Buildings. From storage, grain is unloaded (Sweeps, Auger, Chain, Manual) and elevated (Inclined chain single double auger, Vertical bucket belt chain auger blower). The elevated grain can be used for CASH GRAIN (Truck straight pick up semi, Wagon all types) or LIVESTOCK (Blender-Grinder, Grinder-Mixer stationary portable). The cash grain is then transported (Truck straight pick up semi, Wagon all types) to the MARKET. The livestock is processed (Blender-Grinder, Grinder-Mixer stationary portable) and conveyed (Conveyor auger chain belt air, Vehicle feed wagon truck wagon) to the MARKET.

```

graph LR
    subgraph Harvesting
        H1[Picker mounted pull type]
        H2[Picker Sheller mounted pull type self propelled]
        H3[Combine pull type self propelled]
        H4[Broadcast vs row 1 to 8 row 20"-40" spacing]
    end

    subgraph Transport_Harvest
        T1[Wagon flat bed gravity bed feed wagon]
        T2[Truck straight pick up semi]
    end

    subgraph Unload_Harvest
        U1[Hydraulic Gravity]
        U2[Hoist, Wheel]
    end

    subgraph Receive_Harvest
        R1[Drive-Over Dump gravity auger chain oscillatory]
        R2[Drag hinged portable]
        R3[Hopper attached separate box, tire]
    end

    subgraph Elevate_Harvest
        E1[Inclined chain single double auger]
        E2[Vertical bucket belt chain auger blower]
    end

    subgraph Dry_Harvest
        D1[In-Bin layer batch]
        D2[Portable or Stationary batch manual automatic recirculating non-recirc. continuous flow horizontal tower]
    end

    H1 --> T1 --> U1 --> R1 --> E1 --> D1
    H2 --> T2 --> U2 --> R2 --> E2 --> D2
    H3 --> T2 --> U2 --> R3 --> E2 --> D2
    H4 --> T2 --> U2 --> R3 --> E2 --> D2

    D1 --> S1[STORE]
    D2 --> S1

    subgraph Store
        S1[Metal Bins round flat hopper]
        S2[Silos concrete steel]
        S3[Wood Buildings crib conv. others]
    end

    S1 --> U3[UNLOAD]
    S2 --> U3
    S3 --> U3

    subgraph Unload_Store
        U3[Sweeps Auger Chain Manual]
    end

    U3 --> E3[ELEVATE]

    subgraph Elevate_Store
        E3[Inclined chain single double auger]
        E4[Vertical bucket belt chain auger blower]
    end

    E3 --> CASH[CASH GRAIN]
    E4 --> CASH
    E3 --> LIVESTOCK[LIVESTOCK]
    E4 --> LIVESTOCK

    CASH --> T3[TRANSPORT]
    T3 -.-> MARKET[MARKET]

    LIVESTOCK --> P[PROCESS]
    P -.-> CONVEY[CONVEY]

    subgraph Process_Livestock
        P1[Blender-Grinder]
        P2[Grinder-Mixer stationary portable]
    end

    subgraph Convey_Livestock
        C1[Conveyor auger chain belt air]
        C2[Vehicle feed wagon truck wagon]
    end
  
```

The flowchart illustrates the grain handling process, starting with Harvesting (Picker mounted pull type, Picker Sheller mounted pull type self propelled, Combine pull type self propelled, Broadcast vs row 1 to 8 row 20"-40" spacing) and Transport (Wagon flat bed gravity bed feed wagon, Truck straight pick up semi). The process continues through Unload (Hydraulic Gravity, Hoist, Wheel) and Receive (Drive-Over Dump gravity auger chain oscillatory, Drag hinged portable, Hopper attached separate box, tire). The grain is then Elevated (Inclined chain single double auger, Vertical bucket belt chain auger blower) and Dried (In-Bin layer batch, Portable or Stationary batch manual automatic recirculating non-recirc. continuous flow horizontal tower). The grain can then be Stored (Metal Bins round flat hopper, Silos concrete steel, Wood Buildings crib conv. others) and Unloaded (Sweeps Auger Chain Manual) before being Elevated (Inclined chain single double auger, Vertical bucket belt chain auger blower) for Cash Grain (Truck straight pick up semi, Wagon all types) or Livestock (Blender-Grinder, Grinder-Mixer stationary portable). The Livestock path leads to Process (Blender-Grinder, Grinder-Mixer stationary portable) and Convey (Conveyor auger chain belt air, Vehicle feed wagon truck wagon).

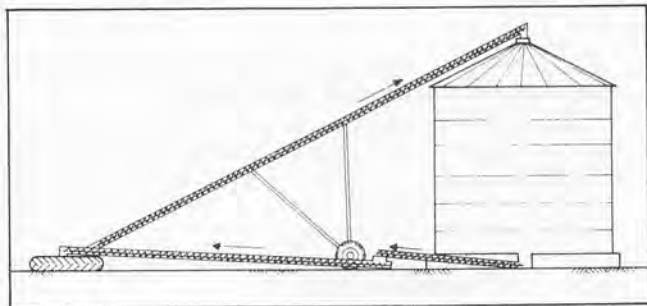


Fig 431-5. A closed handling loop with inclined conveyor and horizontal bin unloaders and conveyor.

Inclined conveyors can also be used in closed handling loops.

The inclined (filling) and horizontal (emptying) conveyors must be moved from bin to bin. Bins are usually located in a semicircular pattern. But expansion and future use of a vertical elevator is easier if the bins are in a straight line. Fig 431-6.

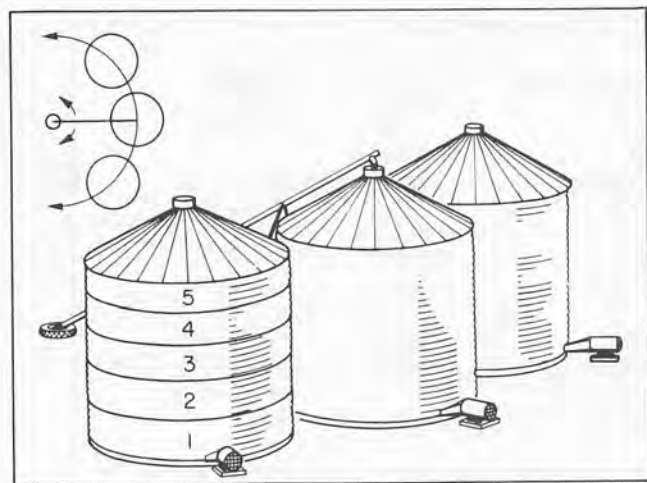


Fig 431-6. A semicircular bin cluster for an inclined conveyor.

FLOW PRINCIPLES

Gravity flow is not free in materials handling. You spend money to elevate the material above grade so that it will flow back by gravity. Gravity flow is frequently the most convenient method, but may be highest in cost, and should be applied only where its special characteristics are essential to the process.

Overhead bins require extra supports. These must be repeated for each bin. Elevated bins also have greater fill heights, requiring taller elevators. In contrast, ground-level bins are lower in fill height, and rest on the ground, which simplifies construction.

A hopper bottom can be installed in a bin to give 100% free flow of material.

A bin-sweep unloader in a flat-bottom bin gives complete unloading, mechanically. The sweep unloader removes material from the floor after gravity flow to the bin center outlet has stopped.

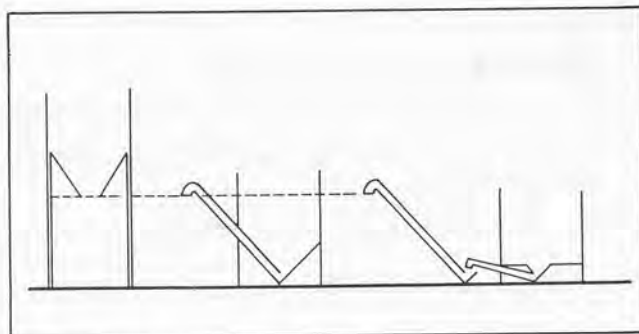


Fig 431-7. Three alternative ways of obtaining elevated discharge plus complete bin emptying.

The hopper construction is permanent and must be repeated for each bin. It is costly because of both extra construction and reduced storage capacity. The sweep, in contrast, requires little special construction, wastes no storage volume, and can often be moved from bin to bin. If storages are unloaded in rotation throughout the year and sweep performance is adaptable to the material, cost savings can be sizable.

MATCHING COMPONENTS

Tandem (one after another) conveyor and process elements are common in most farm-materials handling systems. All components must be matched in capacity, or surge bins added in the flow stream to buffer dissimilar rates. In a continuous-flow process, the smallest-capacity unit controls the total flow rate.

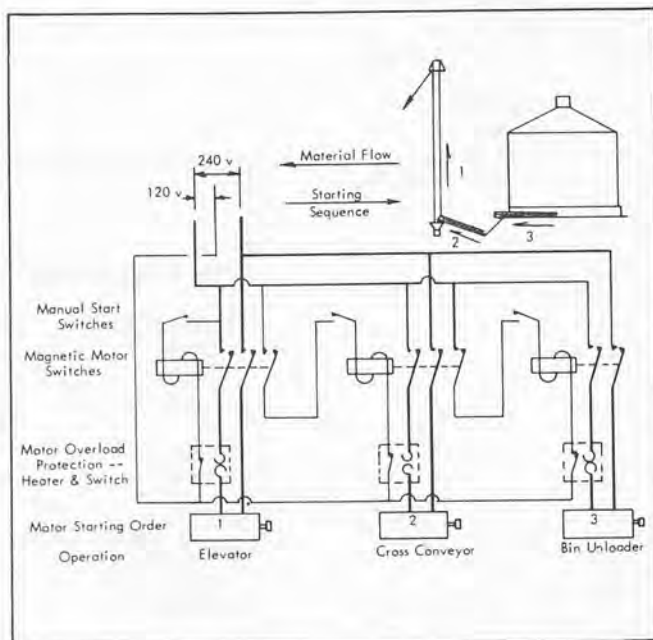


Fig 431-8. Motor controls for conveyors in sequence.

However, interlocking the units electrically to prevent starting in the wrong sequence is very easy with magnetic motor starters, and is recommended for all conveyor "train" installations. In

such an arrangement, the last element in the process is started first, which then feeds power to the next control for manual starting. The second is started manually after this first is up to speed; which then feeds to the next, once started and so on. Its switch activates the next motor's starter coil, etc.

This control technique protects against an over-run of material if the motor on one element should overload. The overload causes the control contact to drop out. Power to the controls on all components feeding this conveyor is interrupted, stopping the feed-in. Any process elements beyond the overload point will continue to run with no material, but with no harm, provided they can be run empty.

Reduced flow rates can encourage smaller equipment, but the total material handled will be the same, and will probably increase with farm growth.

SYSTEM PATTERNS

The flow patterns developed under the discussion of closed-loop handling can be applied to a number of grain-feed handling system layouts. These layouts are based on:

- building one unit at a time—over a period of time, or all at once;
- fitting all types of drying methods;
- containing space for on-farm processing and feed preparation; and
- leaving growth room for alternative handling methods and storage facilities.

A basic pattern is shown in Fig 431-9.

It includes a group of bins located about a center building, with the driveway and vertical-elevator grain dump as focal point of the layout. The center building includes a central work tower containing mechanization and overhead hoppers work bins. The building has a single-slope shed roof away from the work tower.

This arrangement groups all processing at one end of the building. It has room in the center building for a truck scale. There are two positions for a high-speed dryer. With the grain dump positioned only 4' from the work tower end of the building, trucks can be hoisted outside the building, eliminating need for high inside roof clearance. The dryer position parallel to the drive can be used when space is not available between the bins on the left, as in adapting to an existing row of bins.

Several shapes of center building are effective. In Fig 431-10 the building is a work tower with equal sheds both ways. The elevator and overhead bins are located with work space to both sides.

The bin arrangement and high-temperature dryer position of Fig 431-10 permits a larger wet-grain holding bin than Fig 431-9. It is also a better layout for a continuous-flow drying system with two vertical legs; the second leg is placed between the wet holding bin and the dryer. The divided work area is an advantage in some processing-equipment layouts because the overhead bins can directly feed two pieces of equipment, one located on each side of the leg.

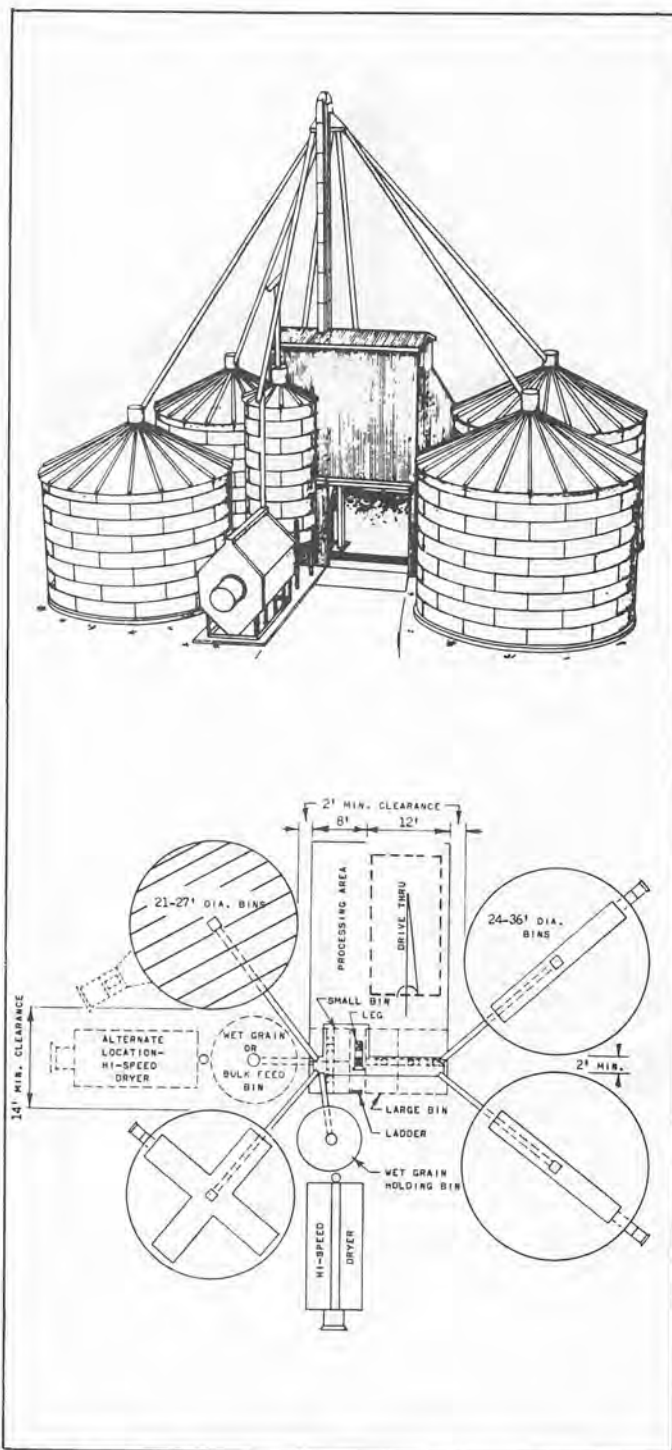


Fig 431-9. A typical pattern (MW Plan 73293) for a grain-feed center. Bins: storage (outdoor), bulk and overhead work (in work tower). Equipment: dump pit, elevator, dryer, scale.

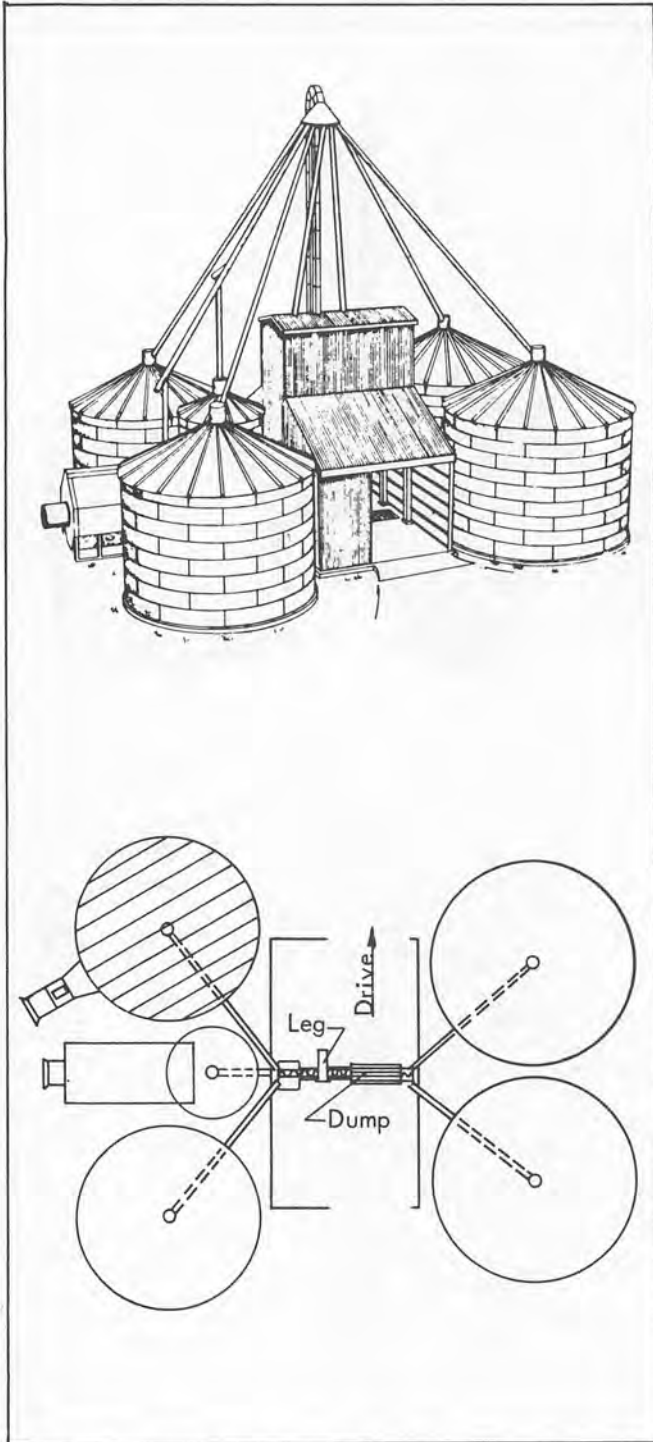


Fig 431-10. An alternative pattern (MW Plan 73292) with handling focal point—dump and leg—in the center of the building.

It was mentioned earlier that it is possible to build for inclined elevators now, and still fit vertical elevators with a center building later.

A sample layout is shown in Fig 431-11. Notice that the bin arrangement shown is exactly the same as that for the completed facilities shown in Fig 431-9, and Fig 431-10, featuring the between-the-bins dryer position. The only difference is the use of the inclined elevator, maneuvered through the space for the future high-temperature dryer and center building.

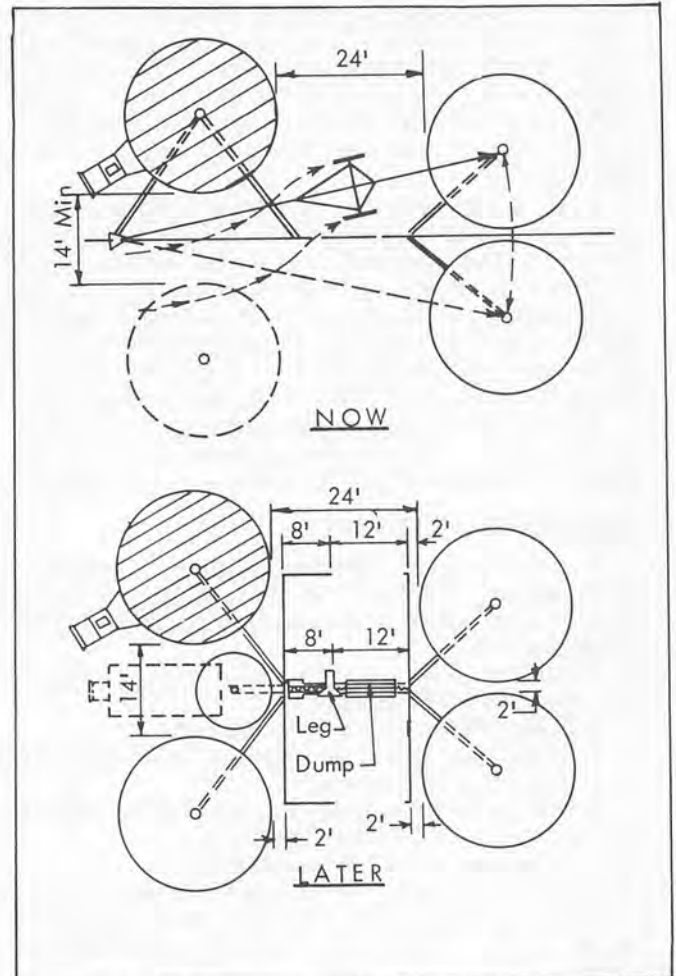


Fig 431-11. A pattern layout for a grain-feed center, adapted for inclined elevator handling. The inclined elevator is maneuvered through the space for the future high-temperature dryer. Note the transition to a complete facility using a vertical leg.

These same basic concepts and patterns for grain-feed centers can be applied in converting double corn cribs to shelled-corn handling. Fig 431-12 shows a crib with a center drive with width and overhead clearance sufficient for grain receiving and dumping.

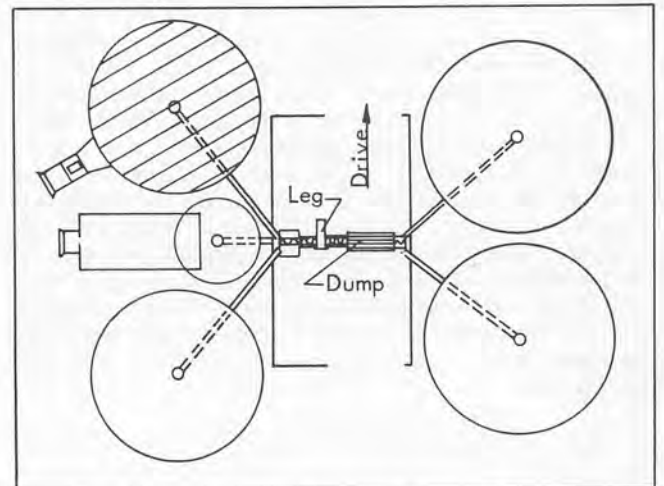


Fig 431-12. A double corn crib adapted to shelled corn mechanization. The drive is used for receiving corn.

SIZING FLOW RATES

The harvesting rate usually dictates basic handling-rate needs, although the drying process or load-out for shipping may govern. The recommendations for four basic handling rates are summarized in Table 431-2.

Handling rates for making feed are very low. For instance, 500 bushels per hour of 60-pound material is 30,000 lb/hr. This is 15 tons per hour, an ample rate for most farms.

In general, bucket elevators are constant-volume devices. The capacity per minute is relatively constant for most grains and moisture contents.

The capacity of screw conveyors varies considerably with changes in the material and in moisture content. Increasing moisture content of corn from 14% to 25% cuts the capacity about in half and doubles the horsepower required—increasing horsepower per bushel by 4 times. In general, augers work better on dry than on wet grain, but they can be satisfactory on wet grain if they have sufficient horsepower, especially on inclined units.

Table 431-2. Recommended sizes of bucket elevators.

CAPACITY Bu/hr	COMMENTS	APPLICATIONS
500-700	Well suited to wet and dry grain handling on continuous flow dryer	1 - Small farm needs 2 - Feed making only, with separate elevators for receiving wet grain 3 - As wet and dry grain elevator on continuous flow dryer.
1000-1200	Well matched to 6" augers. Six inch gravity spouts	1 - Small and medium farms, feed and/or cash grain. 2 - Small batch dryers, and layer or batch-in-bin drying methods on small to medium farms.
1500-2000	Well matched to load-unload rates on many mechanized batch dryers Maximum size for six inch gravity spouts. Maximum size for 8" horizontal augers in 25% corn.	1 - Medium to large farms, feed and cash grain. 2 - Load-unload on batch and batch-in-bin drying systems. 3 - Primary leg in a continuous flow or batch drying setup.
2500-3000	Matched to 8" overhead augers in dry grain. Eight inch gravity spouts	1 - Large farms, feed and cash grain. 2 - As load-unload on large batch and batch-in-bin dryers. 3 - As primary leg in two-leg installations on continuous flow dryers.

FEED-PROCESSING LAYOUTS

All the grain-feed centers shown have room for feed processing. Whether the center is planned for immediate use for cash-grain or grain-livestock doesn't matter. Any cash-grain farm today can be a livestock farm tomorrow, under other economic conditions. Also, the cash-grain farm needs cleaning equipment to take out fines and foreign material, and these need space and work bins.

SAFETY

Materials-flow systems are generally built up on the farm. It is very important that equipment has safety shielding to protect the operator. Since different manufacturers' equipment may be linked, it is impossible for them to prefabricate the needed shielding. Shields must be fabricated and installed by the dealer or farmer.

Electrical equipment must be adequately sized, and properly selected and installed. Locate controls so you can see what's happening, and observe hazardous points.

Common sense and safety precautions around dryers and other equipment are also musts. Dryers have safety controls to protect the equipment and the operator in case of a malfunction. But it is also important that the operator knows how the unit works, so that he can quickly detect when something is wrong. Know the right procedure for safety and correct performance. *Read the instruction manual and know it.*

GRAIN-FEED HANDLING CENTER OPTIONS, Fig 431-13.

The four basic center buildings shown in the first column can be combined with any of the drying and storage layouts to create a wide range of facilities.

The semicircular patterns are the only layouts that restrict the choice of center building. Since the process area of the building is nested within the bin circle, the length of the process area is limited. A symmetrical center-building design is better for these layouts than the one-way structures with the dump close to one end.

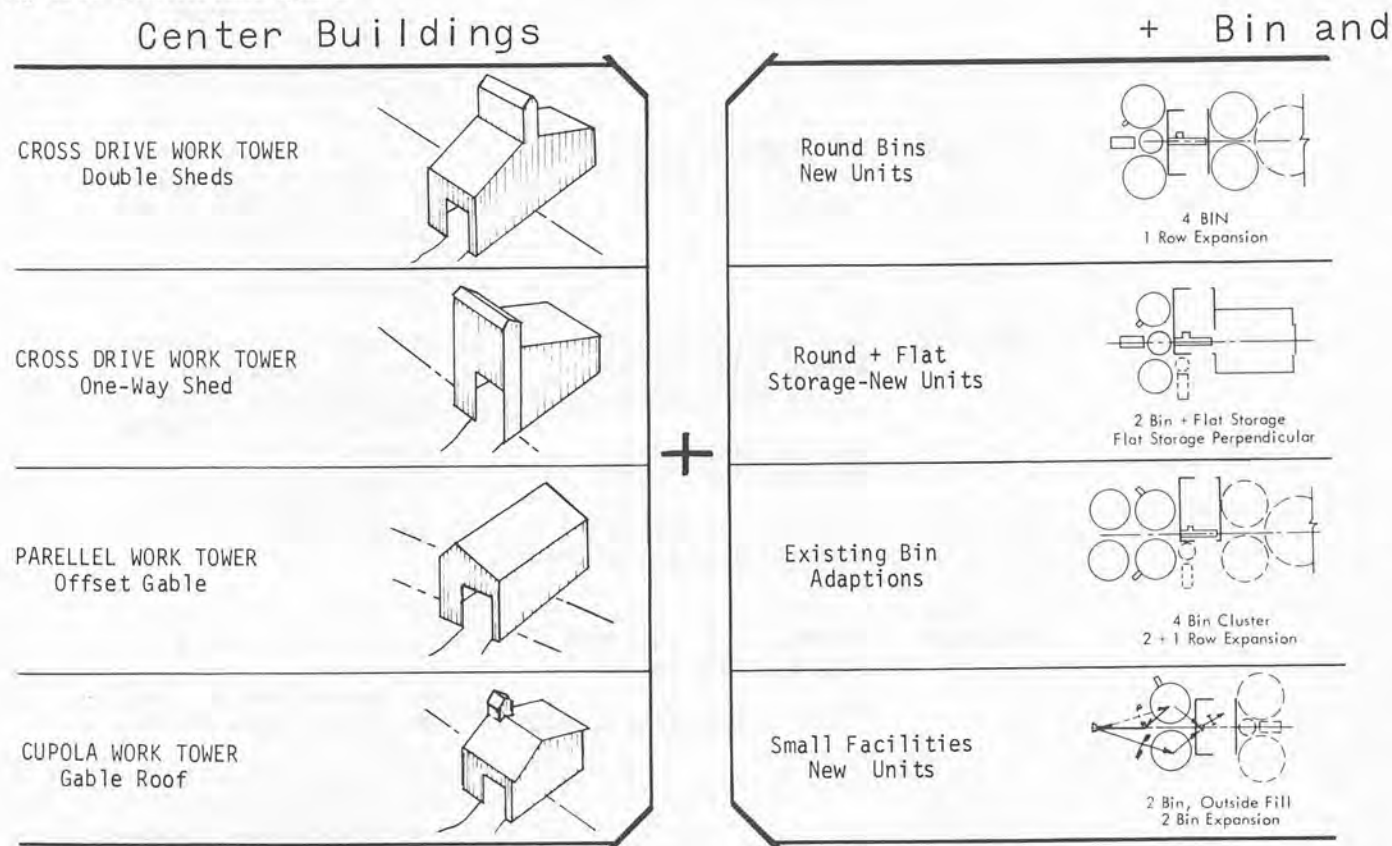
The layouts shown for small facilities are usually combined with the more simple center buildings, to hold costs down.

The layouts using the separated bins for between-the-dryer location permit using inclined-elevator filling and transfer.

Dryers

Note that there are two high-temperature mechanized dryer positions shown on many layouts. The between-the-bins position permits a larger diameter wet holding bin than is possible parallel to the drive. It also works well for a two-leg continuous flow process, since the dry-grain leg next to the dryer need be only tall enough to reach the adjacent bins. Large installations may need two dryers. The dryer position parallel to the drive fits especially well where two existing bins are too close for installation between the bins.

Fig 431-13. Grain-feed center options.



Note also that all plans show both bin and high-temperature drying. Either is satisfactory, depending on the volume and the circumstances on your farm. Both can be used together. Drying methods change according to the volume handled. Leave space for the alternative method—you may need it. The space costs much less than adapting an unplanned layout.

Although batch-in-bin drying is shown, all bins can be adapted for layer drying. The dryer bin should be close to the handling system and to future dryer positions. Thus any investments now are usable after expansion.

Bin Sizes

Having two or three different bin sizes available, as illustrated, is desirable. Two bins of unequal size may be better than having two exactly alike. Volumes of different crops vary from year to year. Also, quality may dictate separate storages, such as for moldy corn at harvest on part of the crop, or distress corn purchased at a good price, but needing separate storage.

The higher initial cost of two smaller storages may be a cheap price to pay for 20 years of more flexible management opportunities. Increasing the storage by one size will usually not save more than 5¢ per bushel on the original investment divided by 20 years of use. In large sizes, costs may be less than 2¢ per bushel.

Small Facilities

These layouts are intended for small livestock farmers. They suggest that he fill the storages from one side and unload (inside a building) from the other. One portable inclined elevator positioned outside serves all receiving and transfer needs. Assuming he practices batch-in-bin drying until the storage bin is full and then layer dries the drying bin full, he might expect the following: 15,000-bushel annual capacity, and a daily batch of about 1000 bushels dried to 14%, cooled, and transferred every 24 hours. If he batch dries one-half of 15,000 bu, or 7500 bu, at 1000 bu/batch he needs to dry 8 batches. This means only 8 elevator moves per year to complete the transfer of the batch-dried material.

Out-of-storage handling in the small facilities shows a separate equipment group, inside the building. These may be portable, either on wheels or overhead track. They may also be 4" auger, rather than 6", 7", or 8" needed for high speed wet grain receiving and batch transfer. The inside conveyor system may deliver directly to a transport vehicle or to feed processing.

The basic layouts of the small facilities are exactly the same as the larger units. Therefore they adapt to high-temperature drying with inside vertical elevators—the transition from small to large is pre-planned.

Dryer Layouts

= Grain-Feed Centers

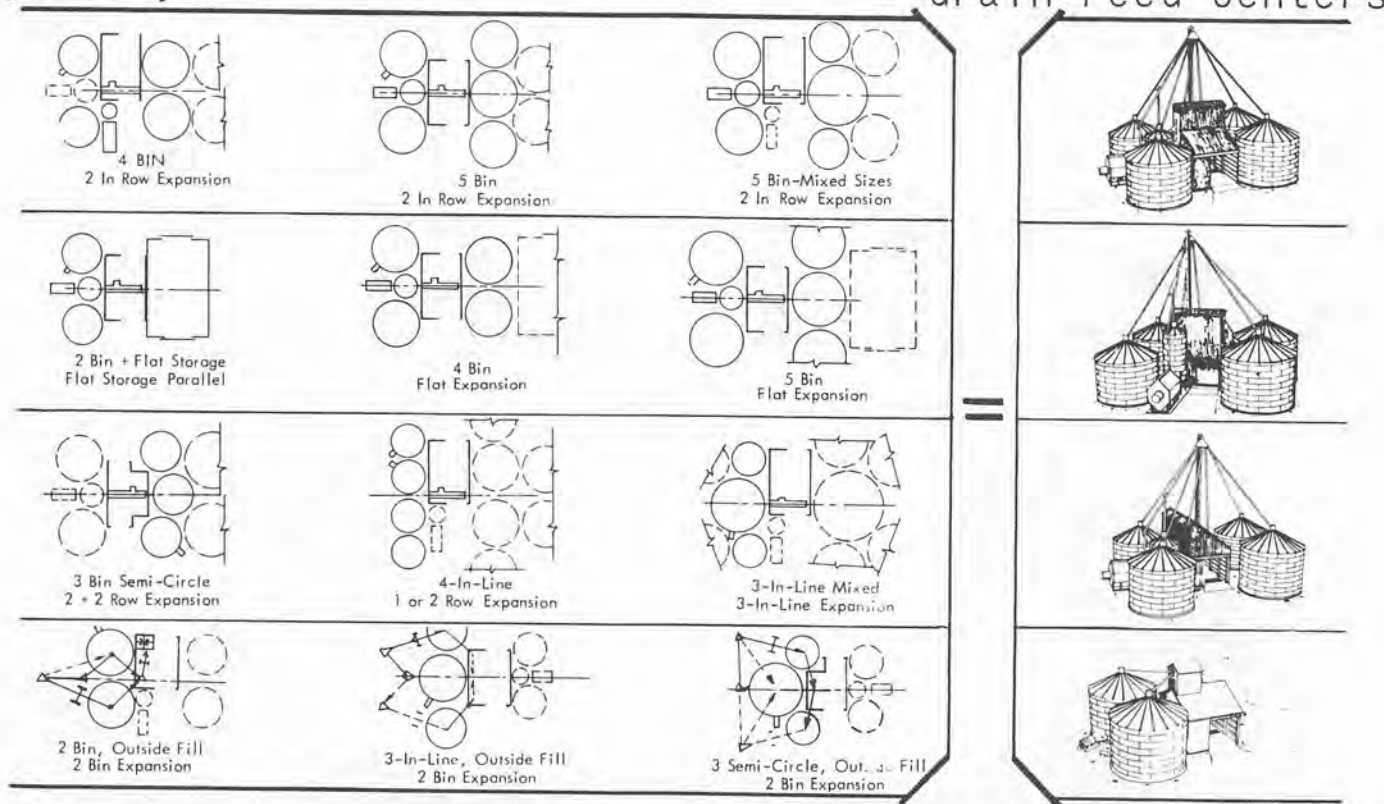
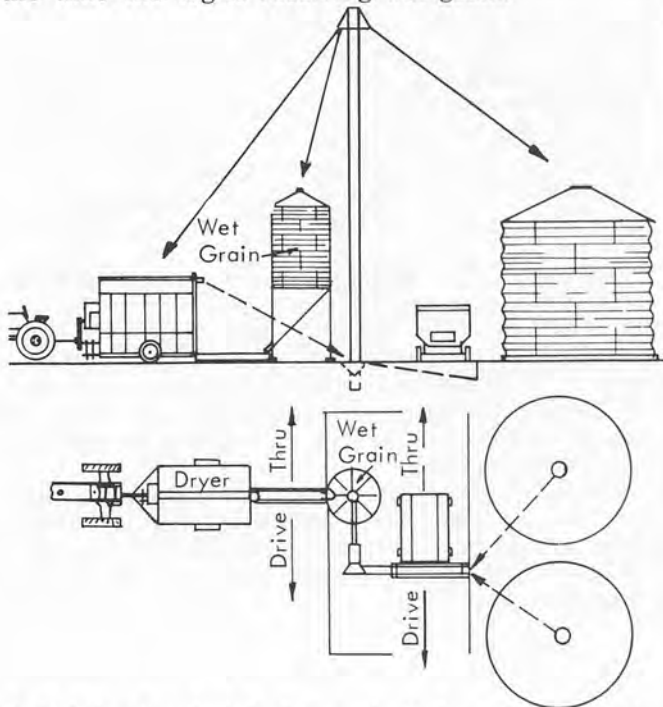
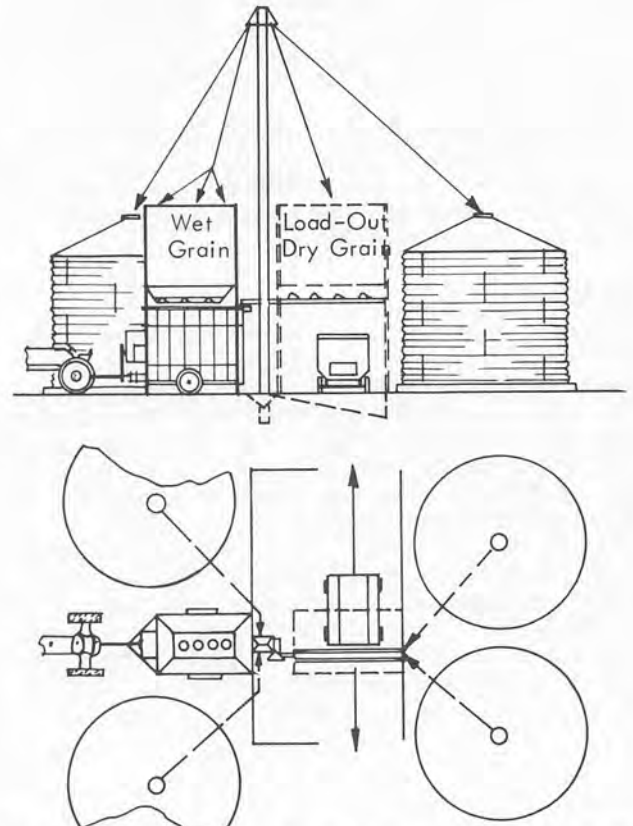


Fig 431-14. Drying layouts for mechanized dryers.

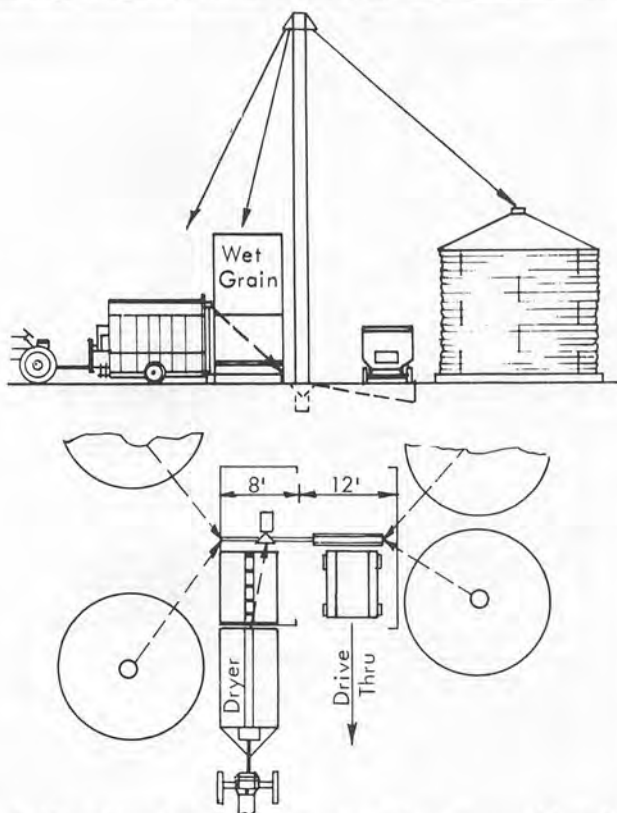
If the dryer is continuous flow, wet and dry grain are handled at the same time. To adapt layouts A and B, dryer discharge must be to a small holding bin or low-capacity conveyor during the time the leg is receiving wet grain.



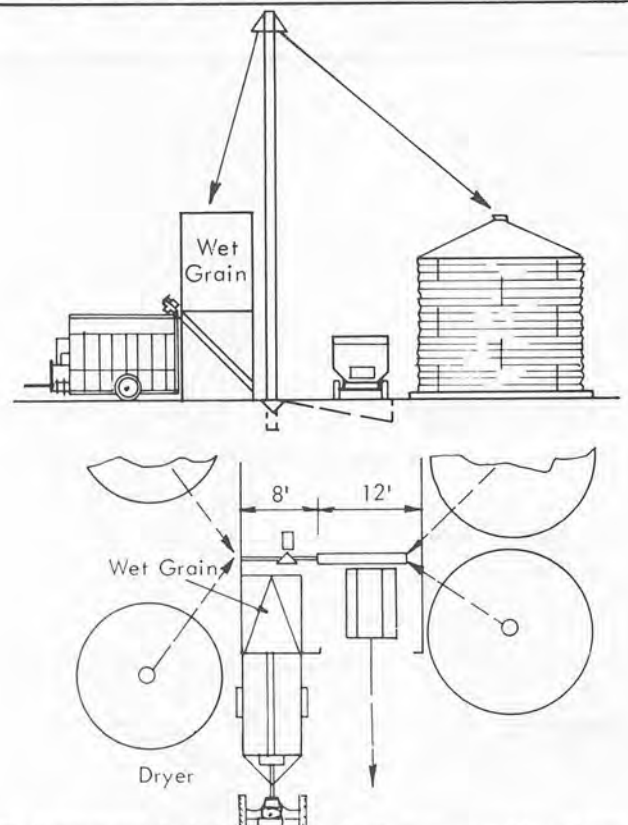
A. Self-loading batch dryer, single leg, ground-level wet holding bin. Dryer fills from dryer dump, wet grain bin, or direct from leg.



B. Gravity-fill dryer, single leg, overhead wet holding batch or continuous flow.

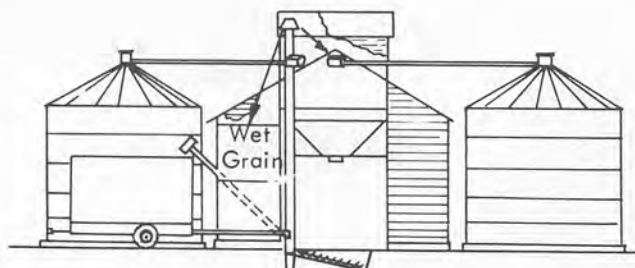
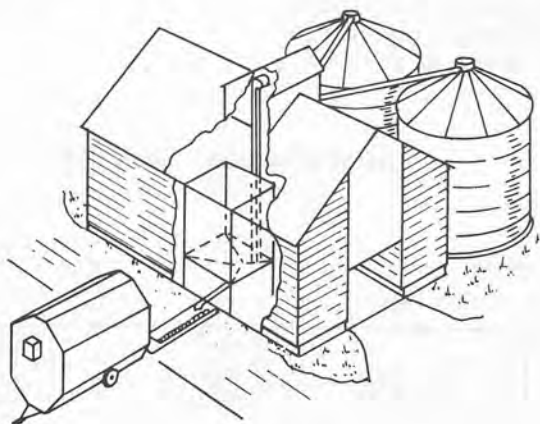


C. Self-loading batch dryer, single leg, ground-level wet holding over dryer self-loading dump.



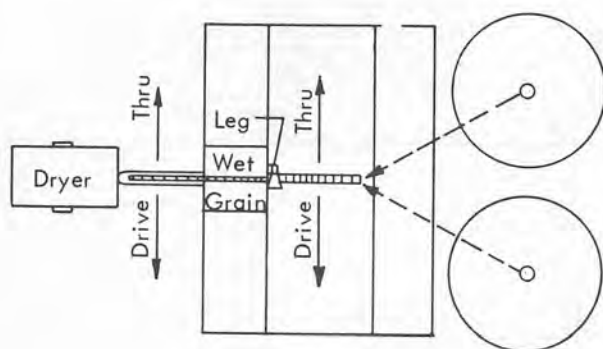
D. Conveyor-fed dryer, single leg, ground-level wet holding. Manual or automatic control batch, or continuous flow.

Fig 431-15. Mechanizing double cribs for shelled-grain handling and drying.



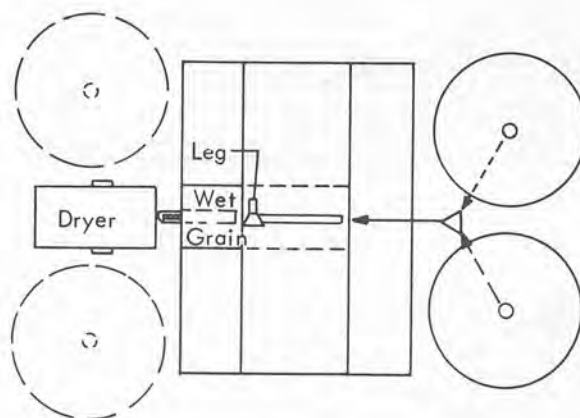
Batch Or Continuous-Flow Installation, Non-Self-Loading Dryer.

Dryer loaded via leg to wet-grain storage to inclined conveyor.



Batch-Dryer Installation, Self-Loading Dryer

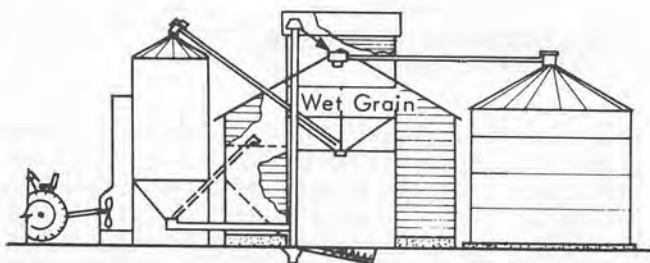
Self-loading dryer dump maintained clear for receiving grain. Dryer may be filled direct, or from wet-grain storage.



Batch-Dryer Installation, Self-Loading Dryer

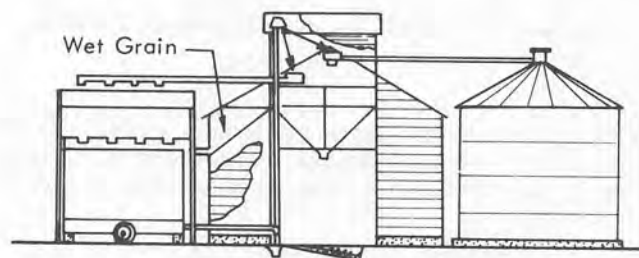
Self-loading dump extended under wet-grain bin. Dryer loading via leg through wet-corn bin only.

NOTE: Self-loading and unloading dryers with grain throwers may throw grain through a spout running through wet-grain bin to discharge into vertical elevator in center drive.



Continuous-Flow Dryer Installation, Single Leg

Leg must run continuously to take away dry corn unless dry-corn accumulator bin (#1) is used. Bin is normally unloaded manually but automatic unloading or dryer stop is possible. Two separate legs, one each for wet and dry corn, can be used and run continuously.



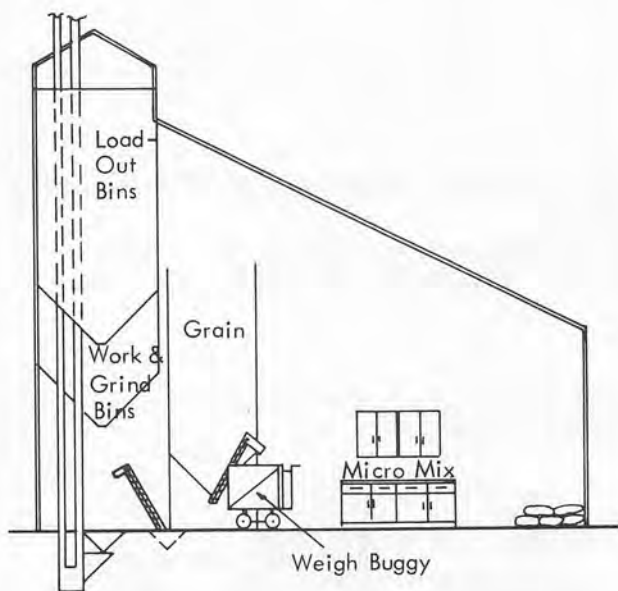
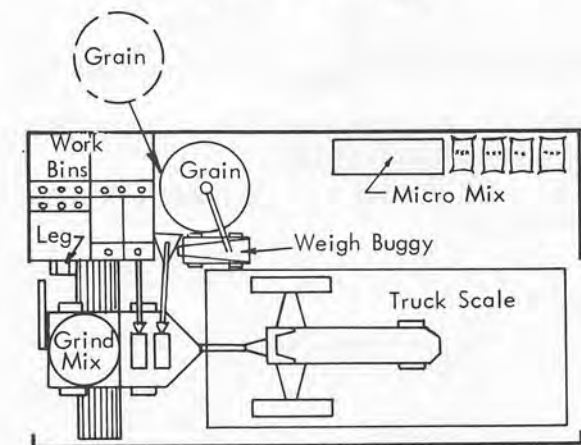
Batch Or Continuous-Flow Installation, Dryer Gravity Filled.

Dryer loaded via leg to wet-corn conveyor over gravity bins.

Fig 431-16. Feed processing layouts transport grinder-mixer.

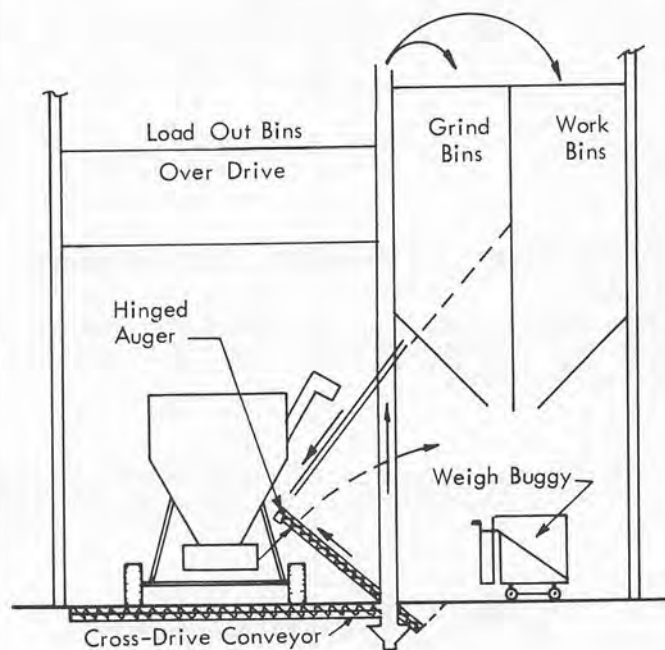
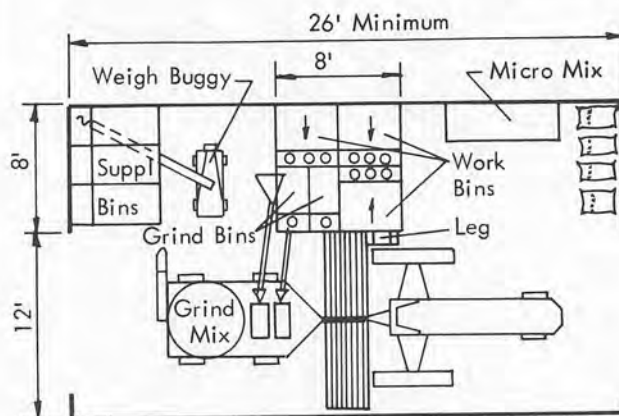
Note that both the layouts on this page fit feed-center layouts described earlier, and use the same center building, handling equipment and work bins as for blender-grinders and stationary grinder-mixers. Thus any method can be used at any point in time.

Offset Building



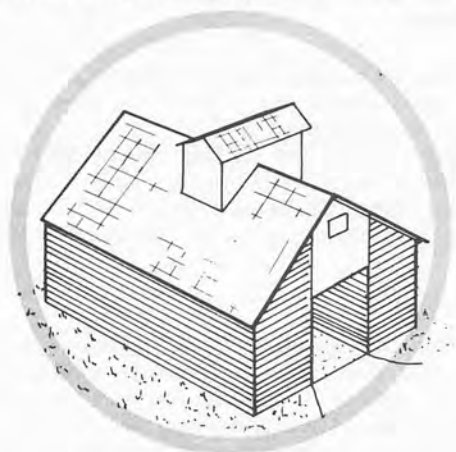
This layout has the same basic flow as the one to the right, except that the work tower is at one end of the building as shown in some of the previous layouts.

Equal-Shedded Building



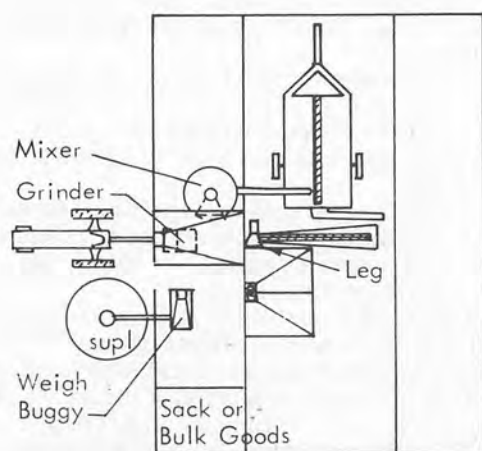
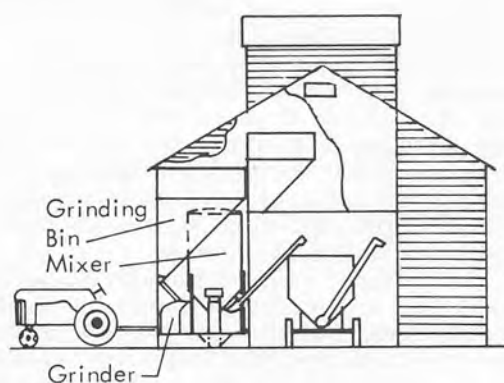
Grain and feed supplies are received through the cross-drive conveyor and the vertical leg. Materials are drawn from the grain bins or work bins into the weigh buggy, then elevated to the grinding bins. These weighed amounts flow into the grinding hopper of the transport by gravity. The weigh buggy is also used to transfer supplements to the underfloor hopper of the small auger-elevator into the supplement hopper of the transport. Materials from the grinding bins and weigh buggy may also be transferred into the hopper of the main leg, and elevated into the load-out bins over the driveway.

Fig 431-17. Feed-processing layouts—ear corn plus shelled grain

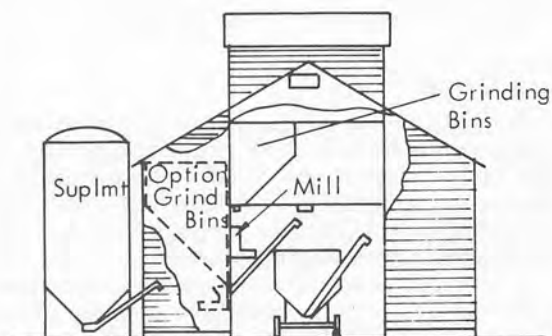
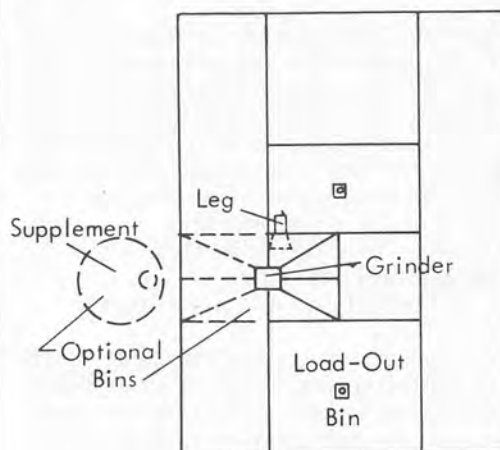


Processing In Double Corn Crib

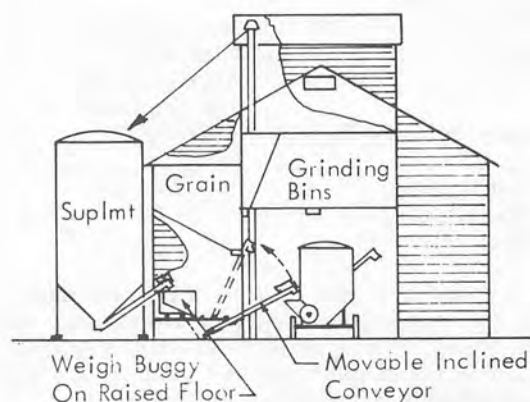
Small overhead hopper-bottom bins are built into existing overhead bins and/or one of the cribs to provide work bins. A leg in the driveway and close to the crib, provides for receiving grains and supplements.



Processing Center For PTO Tractor Grinder.



Processing Center For Transport Grinder-Mixer.



Processing Center for Automatic Blender-Grinder.

CHAPTER 432. EVALUATING STORAGE METHODS

(including selecting a dryer)

The handling, drying and storage methods shown are applicable to most grains, although typical corn-belt needs are emphasized. Most on-farm storages are included, except ear corn in cribs. The best storage system depends on:

- The type and size of farm operation—cash grain, beef feeding, swine production, etc.
- Total annual grain production.
- Harvesting, methods and rates.
- Existing storage facilities.
- Personal experience and preferences.
- Future plans.

Operating procedures are outlined only when needed to better describe the system. Some grains do require special procedures, such as to protect germination when malting barley or seed grains. For additional information on operating equipment or systems, contact your local county agent, extension agricultural engineer, or manufacturer's representative.

Dry Grain

Dry grain can be fed on the farm or marketed commercially. Wet grain can be fed on the farm or perhaps marketed locally, but cannot be marketed commercially. The cost of drying may therefore be partially offset by keeping management options open.

Dry grain is usually selected by swine producers, and for dairy and beef feeding operations up to about 100 head. Large production units often select high moisture grain storage.

Storage tips

You cannot afford to dry grain to a moisture content below that required for safe storage. First, the extra drying takes longer and costs more. Second, the extra water removed from the grain could have been sold at the price of grain.

The recommended moisture content for safe storage of shelled corn held for market is:

Planned Storage Period	Maximum Safe Moisture Content,
	No. 2 Corn
Until spring	15½%
Up to 1 year	14%
More than 1 year	13%

For example, if you dry to 11% (instead of 14% for marketing next summer), you sell 96.6 bushels @ 11% instead of 100 bushels @ 14%. You could have sold 3.4 bushels of water at the price of No. 2 corn.

Aerate grain to help maintain quality in storage. Aeration is low-volume ventilation (about 0.1 cfm/bu) to maintain uniform temperatures throughout a grain mass, and to prevent moisture migration.

After the grain has cooled, and the aeration fans turned off, start them and check the stored grain every 2-3 weeks to help pick up

storage problems. Any foreign or musty odor detected during fan operation may indicate a serious storage problem.

Grain to be fed during the winter can be stored at moisture contents up to 22%, if its temperature can be held below 50°F. Aeration is essential to maintain the low temperature.

Grain drying

Grain drying is often the bottleneck in the total harvesting-drying-storage process. The drying method is usually the key to selecting other grain system components.

Compare drying alternatives first for drying capacity and then for the investment necessary to get that capacity. Many other factors are involved, such as drying temperature, air flow, fan horsepower, etc. But, these factors are not important to selecting the drying method.

Drying systems are generally based on 20 to 25 operating days, available within a 45 to 50 day normal fall harvest season. There is a 90% probability that these 20 to 25 days will be realized, after rainy days and Sundays have been subtracted. Thus, 9 years out of 10, you can expect to harvest 30,000 bushels at 1,500 bu/day in 20 working days.

Actually, other crop harvesting, livestock tending, and machine breakdown cut the number of available days on many farms. A 15 operating-day season gives a realistic system design for many farmers. Harvesting at 1,500 bushels per day average, a 22,500 bushel crop is harvested and dried. Lower or raise the daily rate to fit other volumes.

A very large operator probably cannot afford to design to stay totally within the available 20-25 days. Balance the cost of increased harvest-handling-drying capacity against the value of the anticipated increased field loss due to a severe storm.

Drying and handling needs may change in the future. Leave space in your layout for expansion:

- Increased production requiring more storage.
- Higher harvesting rate requiring wet grain storage and perhaps a different type of dryer.
- Different grains requiring new facilities.
- Additional processes—feed, preparation, grain cleaning, etc.—requiring space for different equipment.

Custom harvesting may increase your daily harvest rate, and therefore the rate at which your center will have to handle the grain.

Commercially available grain dryers include bin, batch, and continuous-flow types.

Types of bin dryers range from low-temperature, in-storage dryers to high-temperature, high-capacity, continuous-flow bin dryers. All of these have storage as part of the dryer.

Batch and continuous-flow dryers are self-contained, column types and are transportable.

Batch dryers include recirculating batch, portable batch, automatic batch, and staged batch dryers.

For each type of dryer review the characteristics and the range of annual production where each is most common. Using a type of dryer outside the suggested range may be satisfactory and economical.

Bin drying systems are illustrated to show typical drying and handling equipment. All possible combinations are not shown; for example, any of the types of bin unloading equipment shown can be used on all grain bins.

The fan is the key to drying capacity for all dryers: air and heat are required for drying.

Fan capacity is expressed in cfm (cubic feet of air per minute); for aeration and drying, cfm/bu is common.

Bin drying systems with insufficient fan capacity are a common problem. Extra initial investment for adequate fan capacity will improve dryer performance and may avoid buying a bigger fan later.

It is difficult to give guidelines for fan selection because fan requirements vary so much with different drying methods. Usually, as fan horsepower increases, drying capacity also increases. Ask your dealer about different fans that are adaptable to the drying bin you select.

Low-Temperature Dryers

A typical low-temperature bin drying system includes a perforated floor installed in a standard grain bin, fan and heat unit, grain spreader, sweep auger, and an unloading auger.

The quantity of corn dried annually is the storage capacity of the bin. The drying air temperature need be no more than 20°F higher than the outside temperature. These are the methods that are most dependent on weather conditions during the drying season—the cooler the weather, the slower the drying rate.

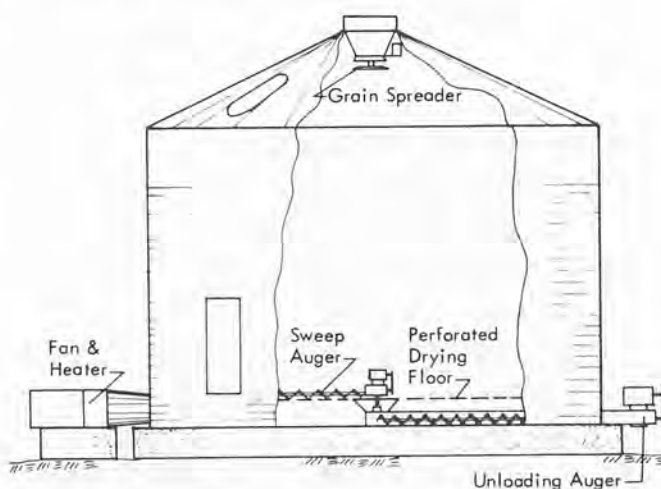


Fig 432-1. Typical equipment for all types of low temperature bin dryers.

These methods require the highest degree of understanding and management of any system. If you select low temperature drying, and whichever filling schedule you plan to follow, you must learn and understand the relationships between airflow, allowable filling rates, moisture content, and temperature. Your state extension agricultural engineer or a manufacturer's representative can help you select the correct fan for your bin and instruct you in proper operating procedures.

Adequate airflow is necessary; install a fan with enough capacity. Screen the grain to remove fines and to help provide maximum airflow through it.

Consider low-temperature drying if you need a new storage and drying system for about 4,000 to 20,000 bushels per year (bu/yr). If you can store all of your grain in one bin, low-temperature drying in that bin will minimize handling.

Multiple-layer dryers

The storage capacity of a multiple-layer drying bin is generally its annual drying capacity. For example, in a 6,000-bushel bin, 6,000 bushels are dried and stored per year.

But, some grain can be dried with high-temperature bin drying methods and then moved to other storage. Then the bin is filled for storage by multiple-layer low-temperature drying.

In multiple-layer drying, the heater control is usually a humidistat that senses when the humidity under the dryer floor is too high. Overdry grain results from incorrect humidity control. LP gas heaters are typical.

Multiple-layer drying requires low labor. But, it is a warm-weather system — harvest as early as possible, because drying is too slow with typical November temperatures.

Don't fill drying bins too fast; the grain might spoil before it is dried. Rule of thumb: Fill a bin with total grain drying depth of 12'

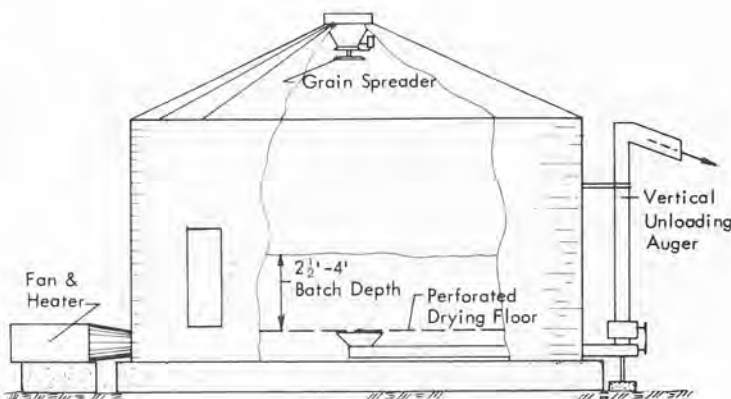


Fig 432-2. Typical batch dryer bin. Use a sweep auger to finish emptying the bin.

in 1 week; 16' in 2 weeks; and 19' in 3 weeks. Several more days of drying are needed after the bin is full.

Because the drying rate is fixed for a given bin, a system not matched to harvest rate may dry too slowly. For a faster harvest rate, consider larger diameter and shorter sidewall drying bins for the capacity you need, even though they cost more per bushel of capacity.

Natural-air and low-temperature in-storage dryers

This method uses the same bin equipment and is very similar to multiple-layer drying. It uses natural air, or a low temperature rise of 5°-8°F. Electric heaters are common. The common recommendation of delaying harvest until the outside average daily temperature is 50°F or less is based on slower spoilage rates in cooler grain.

Select fan size for bin capacity and expected harvested moisture content. With grain at or below that moisture, fill the bin and then dry. If your grain is wetter than that, you must layer dry. Only partially fill the bin to increase the effective cfm/bu; dry the layer; then add and dry the next layer, etc. Even then, the late-harvested grain may not dry, and therefore may spoil in rising spring temperatures about March. Undried grain must be fed, sold, or treated.

However, this system may be operated as a multiple-layer system as described above, without regard to outside temperatures. You may find multiple-layer drying better than delaying harvest until the average outside temperature drops below 50°F.

If you decide to select this drying method, regardless of which filling schedule you plan to follow, you must learn and understand the relationships between airflow, allowable filling rates, moisture content and temperature. Your state extension agricultural engineer or a knowledgeable commercial representative can help you select the correct fan for your bin and instruct you in the proper operating procedure.

Probably the most common mistake with this system is to install a fan that cannot deliver enough air.

High-Temperature Bin Dryers

There are four basic high-temperature bin drying methods: conventional batch drying, stir drying, recirculating or continuous-flow drying, and roof drying. One of these methods is often the least costly system. Drying air temperatures are 120°F-160°F, with the actual temperature depending on equipment, weather, and management. The higher the drying air temperature, the greater the drying capacity. Control drying air temperature with thermostats; humidistats are not recommended. High-temperature drying requires a liquid withdrawal burner, or a vapor burner with separate vaporizer. High capacity burners require adequate safety controls such as high limits, airflow switches, and flame detectors.

Dried grain is moved from a high-temperature bin dryer to other storage; a 6,000-bushel bin can dry over 30,000 bushels per year.

Although steel storage bins are common, farmers often select a high-temperature bin dryer when they convert ear corncribs to shelled corn storage.

Conventional bin-batch dryers

Grain is dried in a 2½'-4' batch depth. Batch size depends on bin diameter and batch depth (Table 2). The usual practice is to harvest, dry, and cool one batch each day in the drying bin and to move it to another storage bin. But, two or possibly three batches can be dried each day.

Limit batch depth so the moisture content of the dried batch varies less than about 5% between the top and bottom. During moving the batch to storage, the wetter top grain mixes with the drier bottom grain.

Deeper layers can be dried with relatively dry grain and relatively high fan capacity. For example, for corn above 25% moisture content, depths of 2½' are usually optimum. When the moisture content is closer to 20%, depths to about 4' are often satisfactory.

Batch drying usually has the lowest initial cost because many bushels are dried in a low-cost bin. But, it requires more labor than an in-storage system because the corn must be moved out of the bin.

Bin-batch drying is very common for about 5,000 to 30,000 bu/yr.

Table 432-1. Bushels per batch in bin dryers.

Bin Diameter, ft.	Approximate Batch Size, bushels			
	Bin-batch drying		Stir drying	
	2½' depth	4' depth	6' depth	9' depth
18'	500 bu.	800 bu.	1200 bu.	1850 bu.
21'	700	1100	1650	2580
24'	900	1450	2150	3250
27'	1150	1850	2750	4100
30'	1400	2250	3400	5100

Batch dryers with stirring equipment

Stirring equipment permits greater batch depths (6' to 9' optimum,) than a conventional bin-batch system. Typically fan size is selected and the batch depth is adjusted to what can be harvested, dried, cooled, and unloaded in 24 hours.

Grain stirring equipment increases the convenience and the capacity of conventional bin-batch dryers, because the bin can be loaded 2½' to 3 times deeper.

With stir drying, moisture often condenses on the sidewalls and soaks grain next to the wall. If dried grain is moved to other storage, this causes no serious problem. But if the grain is left in the bin for storage, this wet

grain next to the wall will spoil. Perforated wall liners or vertical, perforated tubes 9" apart around the wall, reduce wet grain problems. Also, there is less condensation at lower drying temperatures, or if the drying is done during warmer weather.

Stir drying is usually appropriate for drying about 10,000 to 50,000 bu/yr.

Bin-batch and stir-batch drying

For either method of batch drying, equip bins with unloading augers under the perforated floor, and with conveyors to move dry grain to storage at a minimum rate of 2,000 bu/hr.

Arrange the conveying systems to move dry grain conveniently. Bucket elevators (or "legs") can be used, but a combination of portable conveyors and permanent overhead augers is less expensive and about as convenient,

A convenient control for batch drying methods is a 24-hour time clock. The timer is set to turn off the burner when you estimate a batch will be dried. The fan stays on to cool the grain.

Recirculating or continuous-flow drying bins

Bins with recirculating or continuous-flow equipment are used in two quite different ways:

- The equipment is used as a continuous-flow dryer.
- Grain is recirculated in the bin until it is dry, as with stir drying.

This drying method is appropriate for about 10,000 to over 50,000 bu/yr.

Continuous flow

This equipment is best used as a continuous-flow dryer. Shallower corn depths (4'-6'),

are preferred over greater depths for faster drying. However, greater depths can provide substantial wet corn holding capacity. Convey dry grain, still hot, to storage bins for cooling with aeration equipment.

Separate cooling bins (often small, older in-storage drying bins) are also satisfactory, but increase handling because the cooled grain must then be transferred to storage. Two cooling bins add flexibility.

With the same fan capacity and drying temperature, a bin has more capacity as a continuous-flow dryer than with stir drying. Continuous-flow drying eliminates the grain cooling time in the drying bin and also avoids stopping drying to transfer grain to storage.

Since the drying rate is usually 125 to 250 bu/hr, dry grain is moved from the dryer at low conveying capacities, a major advantage for this method. A 6" auger at low rpm is adequate.

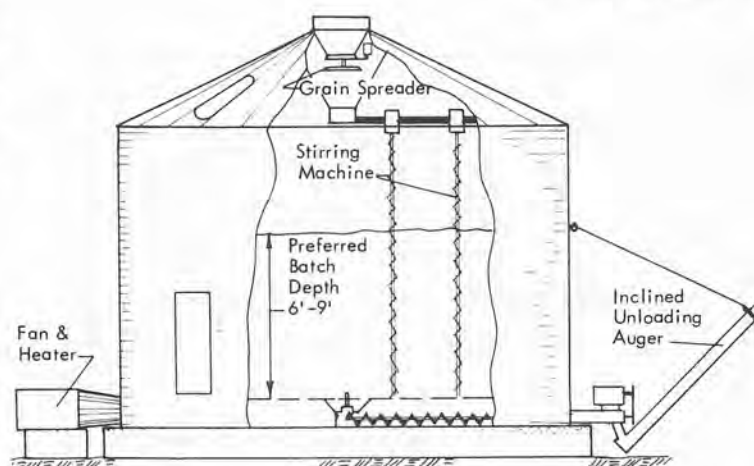


Fig. 432-3. Bin dryer with a double auger stirring device.

Use a sweep auger to finish emptying the bin.

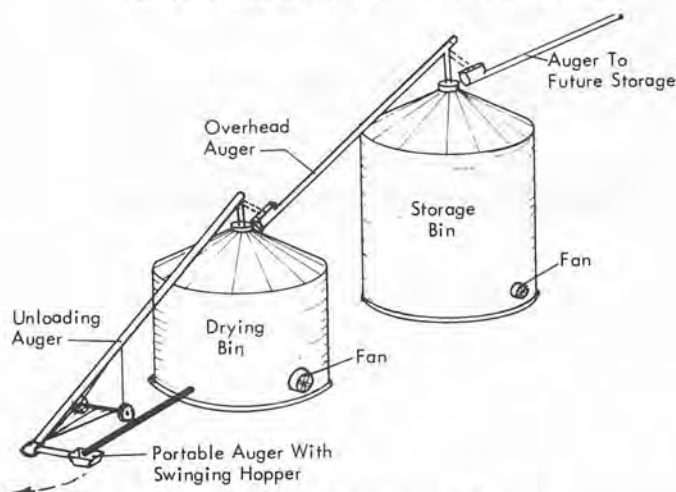


Fig 432-4. High temperature bin drying system.

Load dryer with portable auger. Unload dryer to the same portable auger, which now conveys dry grain to the overhead auger to storage.

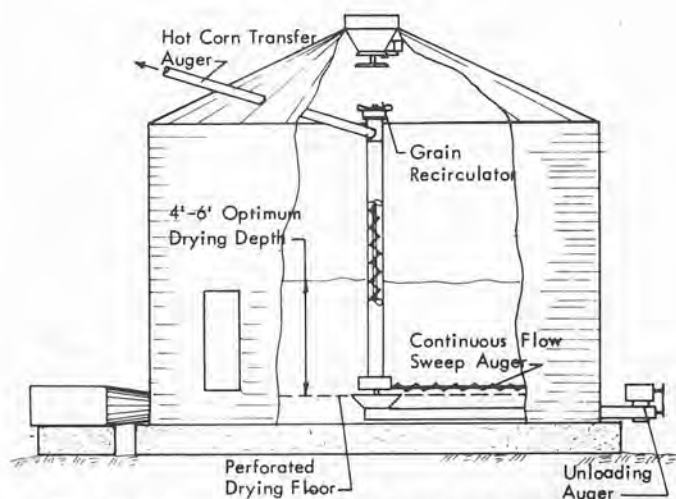


Fig 432-5. Continuous flow or recirculating drying bin equipment.

At least one additional storage bin equipped with aeration for cooling is most common with this drying method.

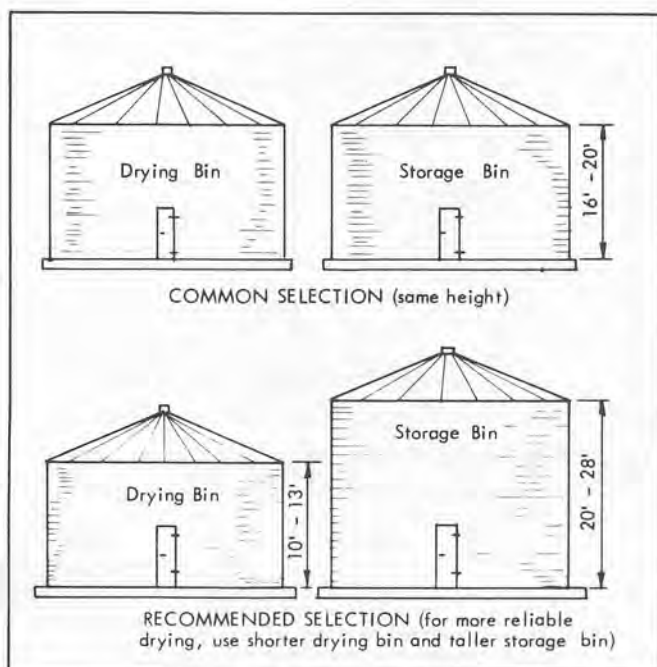


Fig. 432-6. Relative bin sizes for drying and storage.

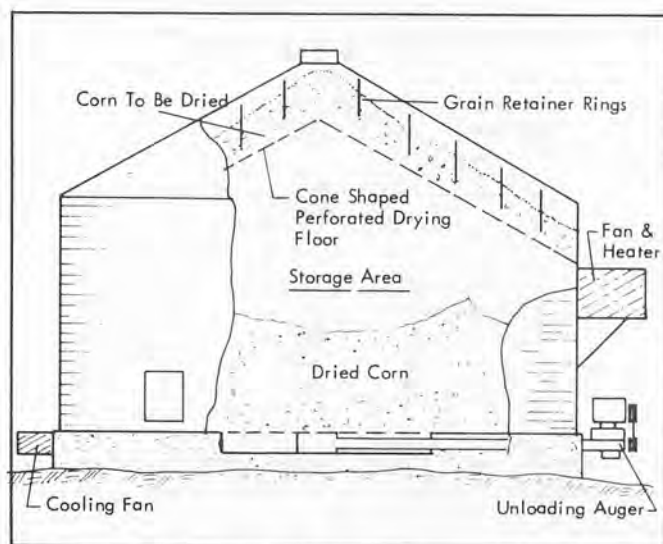


Fig 432-7. Roof drying system.

Additional dry grain storage is common and preferred.

Recirculating

A continuous-flow bin dryer is commonly used as a recirculator to dry the grain that is to be stored in the drying bin. Dry grain from the bottom of the bin is put on top of the wet grain instead of being delivered to storage. Equip a bin for this system with perforated wall liners, or tubes, as discussed in "Batch dryers with stirring equipment." Leave the fan running after drying is complete until the grain has cooled.

Bin-batch, stir batch, and continuous-flow bin dryers

Consider drying bins in any of these three systems first as dryers, and second as in-storage drying bins. Grain dried and stored in the drying bin should be checked frequently, and preferably removed by spring.

Grain stored in these drying bins is more apt to have some spoilage than grain transferred from these bins to storage, so use grain out of the drying bins first.

To increase the reliability of these three methods and to reduce management problems, consider a drying bin with a relatively shallow drying depth (10'-12') as in Fig. 20. Short bins more nearly match recommended drying depths, and there is less grain to have problems with in-storage than tall ones of the same diameter.

For example, assume you need one drying and one storage bin for 15,000 bushels. Instead of two 7,500-bushel bins, consider a 5,000-bushel drying bin (about 27' diameter, 12' deep) and a 10,000-bushel storage bin (27' diameter, 20' deep).

Consider not drying grain in the dryer if it is to be fed out during winter. This practice works well with grain at 22% moisture or less, and average 24-hour temperatures below 50°F. Operate the fan during cool night hours to lower grain temperature.

Roof drying

Grain is dried in a fixed batch up to 32" deep on a cone-shaped perforated floor installed under a bin roof.

Four batch sizes are available: 21' diameter bin, 750 bu; 24', 1,000 bu; 27', 1,300 bu; 30', 1,600 bu.

One to three batches per day can be dried. Grain can be cooled in the roof dryer, but drying capacity is increased by cooling in the storage area.

There is no bottleneck in handling dry grain: the dry batch is dumped into the storage area in 1 or 2 minutes, while cooled grain can be conveyed slowly to other storage.

A roof dryer has no wet grain holding. To dry more than one batch per day, provide wet holding for grain harvested while the previous batch dries. Grain is commonly held in wagons or trucks, but hopper-bottom wet grain holding bin adds flexibility and convenience.

Roof drying is suitable for 10,000 to over 50,000 bu/yr.

Portable Batch Dryers

Probably the main advantage for portable batch dryers is their self-contained drying and handling systems. They are the easiest to move from farm to farm; only the dryer, LP gas tank, and one conveyor from the dryer into dry storage needs to be moved. They are useful at different storage locations or for custom operators.

Their disadvantages are a relatively high labor requirement for loading and unloading the dryer, and the 15,000 to 25,000 bu/yr needed to economically justify a new portable batch dryer.

Good used batch dryers are often available from trade-ins for higher capacity, automatic batch or continuous-flow dryers. Used dryers can be economical for as little as 10,000 bu/yr, particularly if adequate storage is available.

Automatic-Batch And Continuous-Flow Dryers

High capacity (100 bu/hr and up) automatic-batch and continuous-flow dryers are only part of a complete grain handling system. Also include facilities for receiving and holding wet grain, and conveying wet grain to the dryer and dry grain to storage. To be economical, such a system is usually large—30,000 bu/yr or more.

A lower annual drying rate may justify a lower capacity, and therefore lower cost, dryer. Portable wet holding bins, portable conveyors, and used dryers are typical in these systems.

Grain conveying

The choice of appropriate grain conveyors greatly affects the cost and convenience of a system. But cost and convenience are not necessarily related, so a relatively low-cost system can be very convenient if well planned.

Provide for moving grain where needed, fast enough (bu/hr), and with minimum labor.

There are both **fast** (about 2,000 bu/hr minimum) and **slow** (about 1,200 bu/hr maximum) conveying needs. For example, **rapidly** unload wet grain from trucks or wagons; move dry grain from a continuous-flow dryer to storage slowly. Inclined portable conveyors are low cost, and are convenient if sized to need and organized into a system. Select and organize equipment to your system's specific conveying needs.

Another system uses a bucket elevator (leg),

for most conveying. While often the most expensive, a leg is suitable for drying systems handling more than about 75,000 bu/yr. Vertical legs are excellent for a feed processing system, because they are nearly self-cleaning—little material is left in the conveyor.

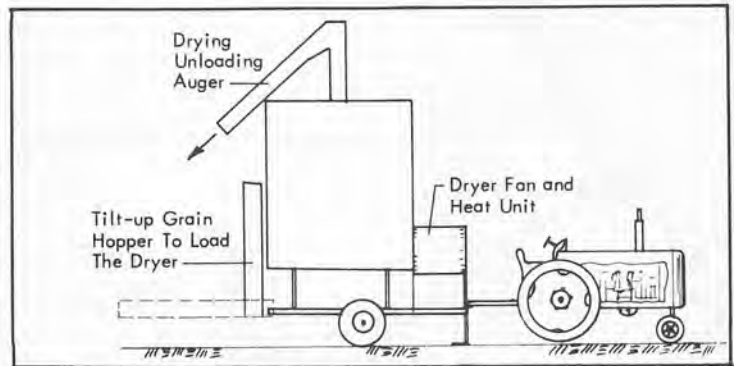
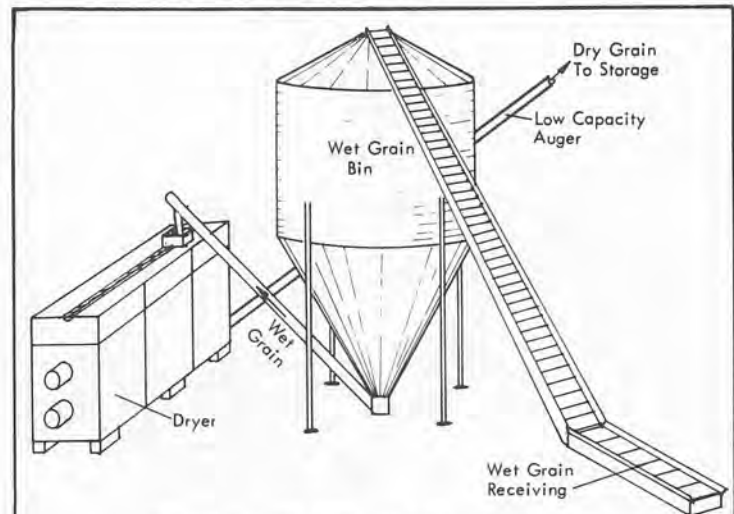
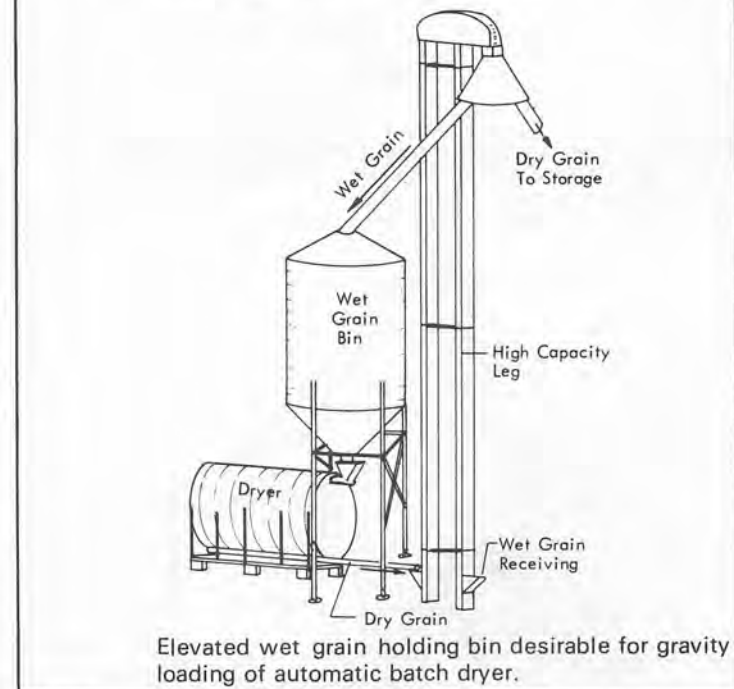


Fig 432-8. PTO powered portable batch dryer with self-contained grain handling.



Ground level wet grain holding bin typical for continuous flow dryers.



Elevated wet grain holding bin desirable for gravity loading of automatic batch dryer.

Fig. 432-9. Automatic batch and continuous flow drying systems.

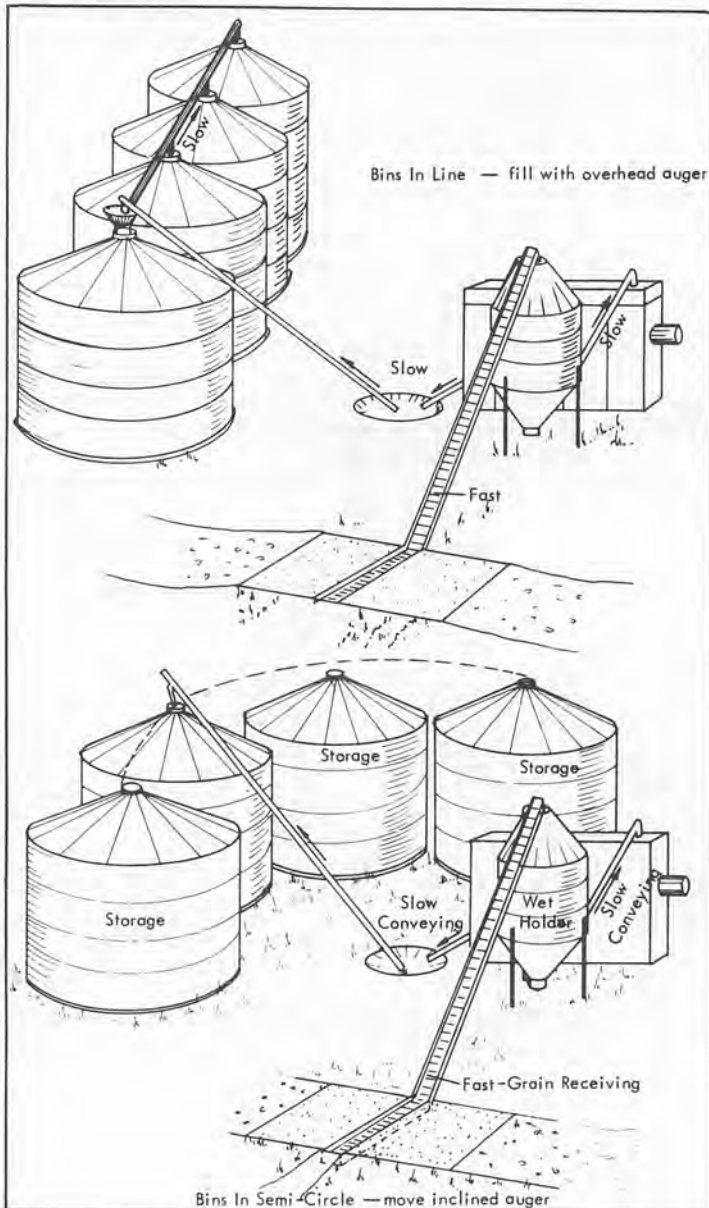


Fig. 432-10. Convenient low-cost grain handling systems.

The dryers are low capacity automatic batch, or continuous flow, units.

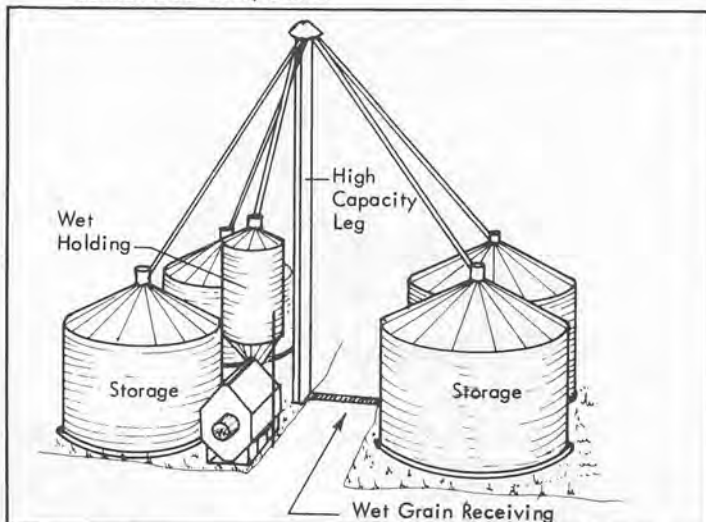


Fig. 432-11. High capacity grain handling system.

High capacity automatic batch dryers require fast wet grain loading.

Grain receiving

Plan for fast unloading of trucks or wagons carrying grain from the field. Estimate the unloading rate needed to have wagons available in the field. For example, 250-bushel wagon can be unloaded in 15 minutes into a 1,000 bu/hr conveyor; 5 minutes into a 3,000 bu/hr conveyor; and in 2 to 3 minutes into a below-ground pit.

Plan for convenient vehicle access. Avoid requiring backing a truck or wagon to unload, which is dangerous as well as inconvenient. Pave the grain receiving area to facilitate cleaning up spilled grain—slope pavement away from hoppers and dumps.

Above-ground hoppers include swinging or fold-down types to convey grain into an auger or vertical leg. Keeping the conveying system above ground is important in poorly drained soils. Above-ground hoppers are almost always the lowest cost, but are less convenient because it is difficult to get spilled grain into the hopper.

Below-ground, drive-over hoppers are more expensive, but more convenient because the receiving hopper does not need to be moved into place.

A relatively large dump pit (about 250 bu) permits fast wagon or truck unloading. Grain flows by gravity to the conveyor emptying the pit. The leg can be fairly low capacity because the pit is a surge bin. Drain deep pits and the soil around them, preferably with tile. If tile drainage is not feasible, install a sump pump.

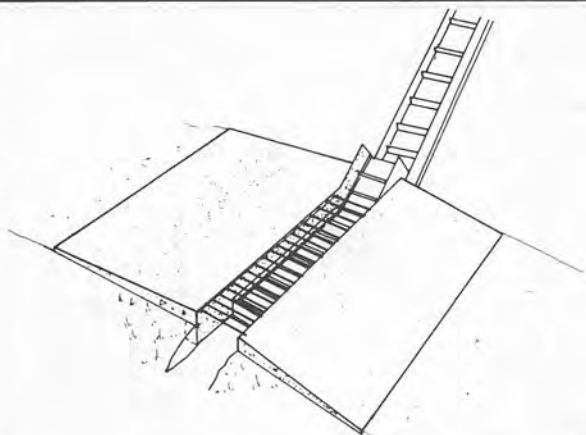
A high-capacity cross-conveyor can replace the large dump pit. Less pit depth can reduce drainage problems. A simple below-ground concrete hopper pit can serve portable inclined conveyors.

Wet grain holding bins

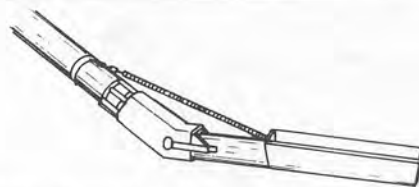
Bins mounted over the dryer permit fast gravity flow into the dryer. Their support usually makes them more expensive than ground-level bins, but they are good for fast dryer filling, such as for large automatic batch dryers.

Grain from ground-level wet holding bins is usually augered to the dryer, although the augers require high horsepower and double V-belt drives. For example, a 3 hp electric motor is required to auger 250 bu/hr of wet corn to a 20' height in a 6" auger at 67½°.

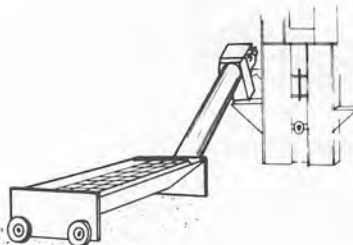
Install wet grain holding bins with capacity for at least 10 hours drying. Hold additional wet grain in wagons, trucks, or aerated storage. Leave space in your system for additional wet grain holding.



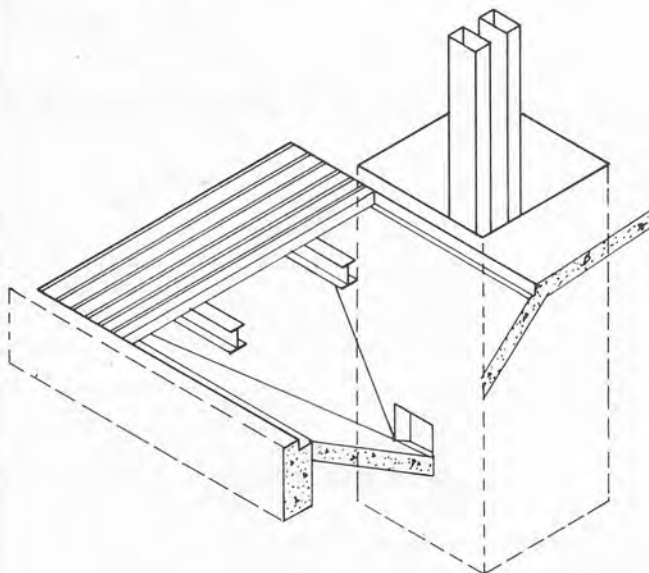
Flight Conveyor (elevator) With A Drive-Over Ramp.
Low cost for moderate capacity with electric motor.



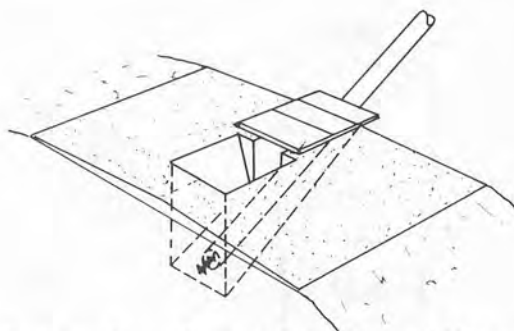
Portable Auger With Tilting Hopper



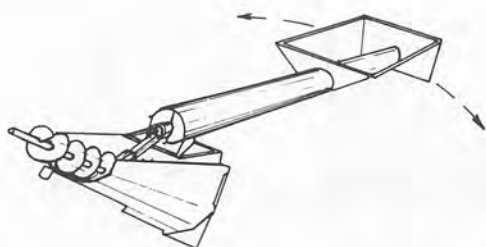
Leg With Swinging Hopper



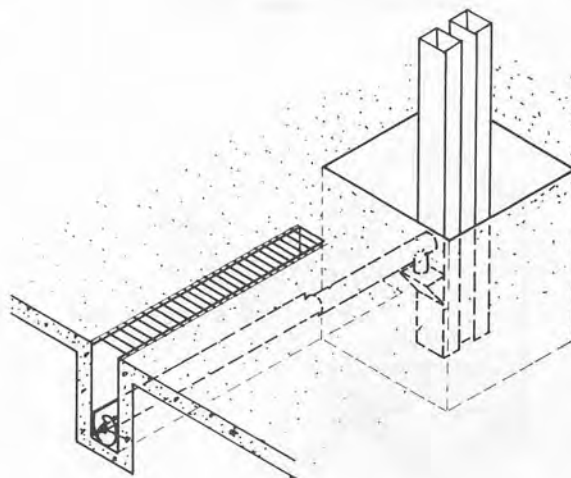
Leg With Drive-Over Gravity Pit, Low Capacity Leg
Adequate



Portable Auger Set Into Below-Ground Hopper Low
Cost for low capacity. Can use high capacity auger
with PTO power.

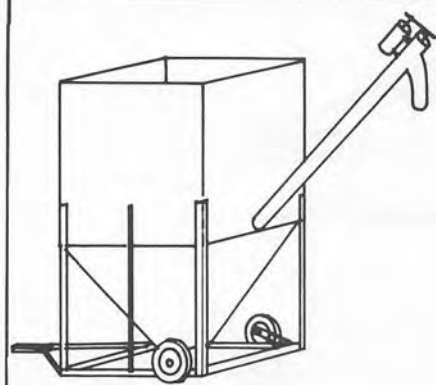


Portable Auger With Swinging Hopper

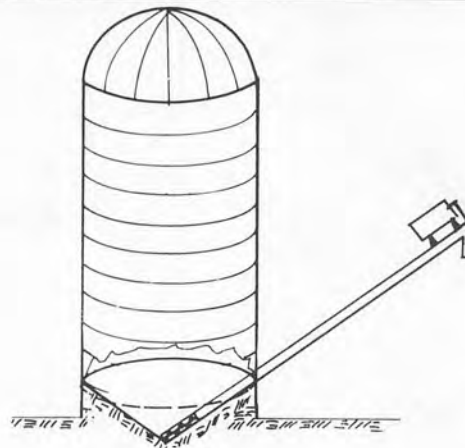


Leg With Drive-Over High Capacity Cross Con-
veyor High capacity leg required.

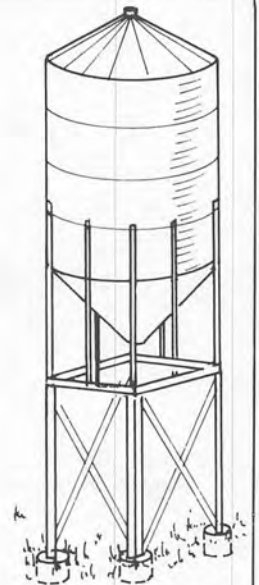
Fig 432-12. Wet grain receiving.



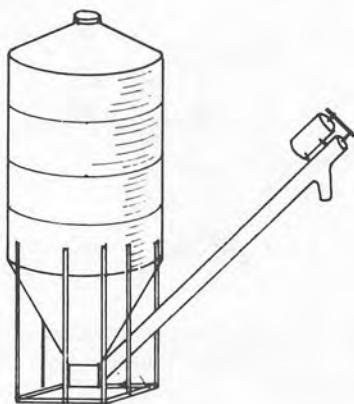
Portable Hopper Bottom



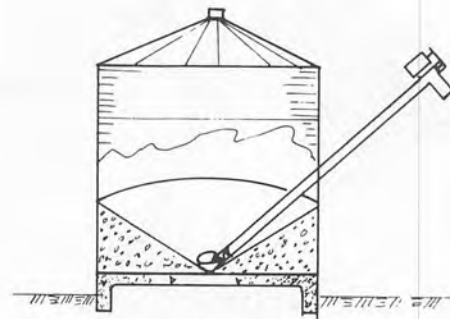
Concrete Stave Silo



Elevated Hopper Bottom

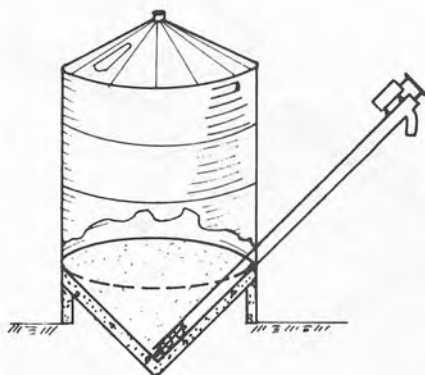


Ground Level Hopper Bottom

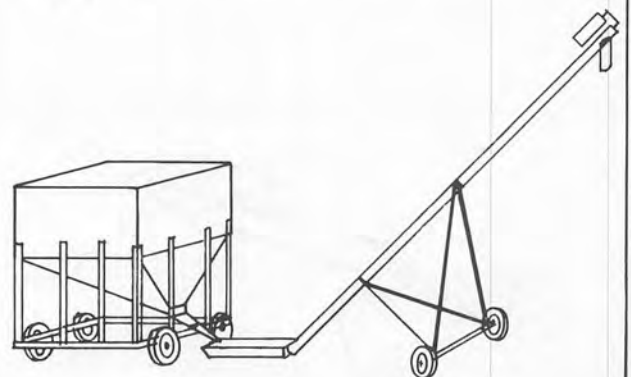


Hopper of Dry Grain

Partially fill bin with dry grain; empty to form "hopper" of dry grain. Every few days rake off a few inches of "hopper" surface; replace with dry grain.



Metal Bin



Side-Unloading Wagon

Two left wheels can be raised to increase gravity grain flow.

Fig 432-13. Wet grain holding.

Cooling dried grain

Dried grain is cooled to minimize moisture migration in storage and to provide a more suitable storage environment. It can be cooled in the dryer, in aerated storage bins, or in separate cooling bins.

Although most grain is cooled in the dryer, the other two methods increase dryer capacity, and minimize stress cracks because of slower cooling. Slowly cooled grain has a better appearance than rapidly cooled.

Cooling grain in aerated bins is easy. Hot grain is usually taken from the dryer at a moisture content at least 1% higher than desired for storage. Aeration equipment speeds up the drying operation by stopping drying with wetter grain and by eliminating cooling in the dryer. A duct aeration system may not assure good air distribution and adequate cooling. Therefore, in storage bins with only ducts, rather than a perforated floor, cool the first 2' or 3' in the dryer, and then begin cooling in the storage.

Separate cooling bins (dryeration) increase drying capacity the most. They can almost double dryer capacity, but require more grain handling. Take hot grain from the dryer 2%-3% above storage moisture content. Delay cooling for about 4 hours to equalize the moisture content within the kernels. Then cool in a bin with good air distribution (preferably a perforated floor) of at least $\frac{1}{2}$ cfm per bushel of maximum daily dryer capacity.

Two dryeration bins are desirable, each holding the maximum daily dryer capacity. One bin is filled one day; the second bin the next day, while the first is being cooled and unloaded.

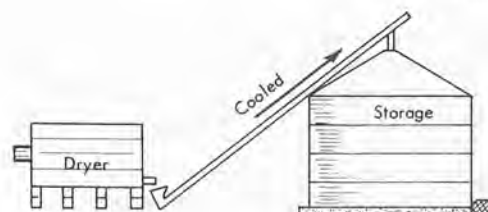
Because of additional investment and labor, most farmers do not include dryeration as they first develop a continuous-flow or automatic-batch drying system. But, do plan a place to add dryeration later.

Conveying dry grain from the dryer

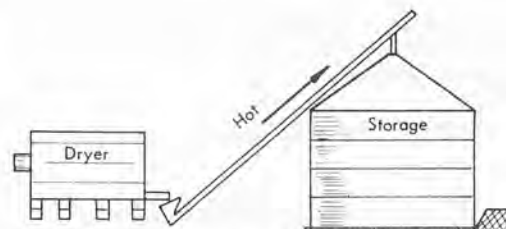
Grain leaves a continuous-flow dryer slowly (about 100 to 300 bu/hr) but almost continuously. But, an automatic batch dryer is unloaded rapidly (up to 3,000 bu/hr).

For continuous-flow dryers, a low capacity conveyor can move dried grain but use a higher capacity conveyor system for wet grain.

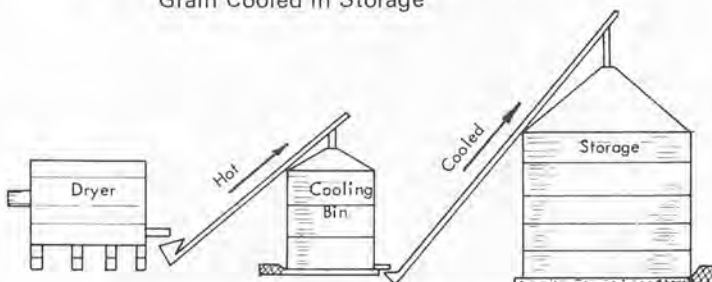
If a single leg is used in a continuous-flow drying system for both wet and dried grain, install a surge tank between the dryer and the leg. Size this tank to accept the dryer output while wet grain is being received, usually up to 15 minutes of the dryer's output, or about 100 bu. This surge bin may be below grade and feed into the back side of the leg, if a large gravity wet grain pit is used. It must be above ground if the rest of the leg is above ground.



Grain Cooled In Dryer



Grain Cooled In Storage



Grain Cooled In Cooling Bin (Dryeration)

Fig 432-14. Cooling dried grain.

Compare costs of systems

Compare different systems on their total initial installed cost per bushel of grain dried annually. For a complete system, separate the storage cost from drying and handling equipment costs.

For example, consider a stirring bin system with filling equipment to cost \$9,000 installed. Assume the bin stores 6,000 bushels and the system dries 20,000 bu annually. The value of the 6,000 bu storage above is about \$2,400, at 40¢/bu. The investment for drying and handling is \$9,000-\$2,400 = \$6,600. That investment, an annual drying volume of 20,000 bushels, is \$6,600/20,000 bu = 33¢/bu.

High-Moisture Grain

It is rare to find a farmer who is not satisfied with high-moisture grain storage, often the easiest and best system.

High moisture grain can be stored in horizontal, sealed, or conventional upright silos. Feed out of a conventional upright silo fast enough (3"-4" per day in summer) to prevent top spoilage. If you cannot feed fast enough, use a sealed silo.

Either high-moisture shelled corn or ground high-moisture ear corn can be fed to beef or dairy cattle. It is normally the least cost and most appropriate method of corn storage for finishing 100 or more beef cattle.

Trench or bunker silos are similar to up-rights for high-moisture grain, but to minimize potential problems:

- Fill the silo as rapidly as possible.
- Cover the surface with plastic or chopped vegetation.
- Remove the grain as rapidly as possible, preferably by late March or early April.
- Grind the grain before storing.

Storing Chemically Treated Corn

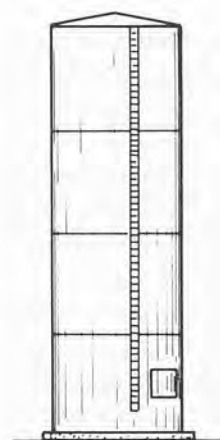
Properly applied grain preservatives marketed by reputable companies prevent spoilage. Effective preservatives contain almost 100% active ingredients—currently propionic acid perhaps with some acetic acid. They reduce the labor of handling grain to about that of high-moisture corn. Treated grain cannot be marketed commercially.

Preservatives may have their greatest application in warm weather swine or dairy feeding of high-moisture grain. The grain need not be fed daily from the storage as with untreated high-moisture grain. The main disadvantage of typical grain treatment is cost, particularly for large volumes or high moisture contents.

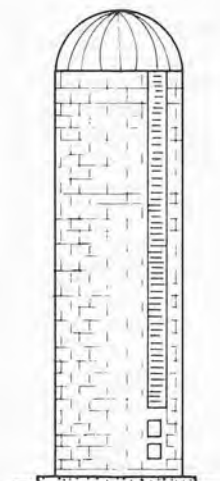
Grain preservatives are practical for storing grain for feeding that can't be dried or put into a silo. For example, treating field shelled corn is more reliable and convenient than piling it on the ground.

Some animal scientists now feel that preservative treated grain has similar feed value as dry grain for hogs and cattle. At this time, there are not complete data on the overall nutritional effect on livestock satisfactory application rates for different moisture contents and storage periods. effects of treatment chemicals on storage structures and handling machinery, etc.

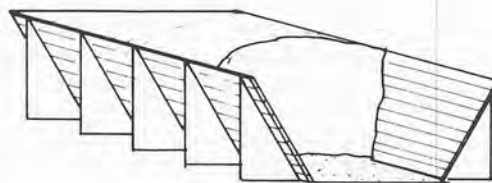
Because of limited experience and knowledge, be conservative. Follow all manufacturer's recommendations on the use, handling, and application of treatment chemicals and the treated grain. Handle the acids carefully, wear protective gloves and goggles, and avoid breathing the vapors or spray mist.



Sealed Storage



Conventional Upright Silo



Horizontal Silo

Fig 432-15. High moisture grain storage.

CHAPTER 433 GRAIN AND GRAIN DRYING DATA

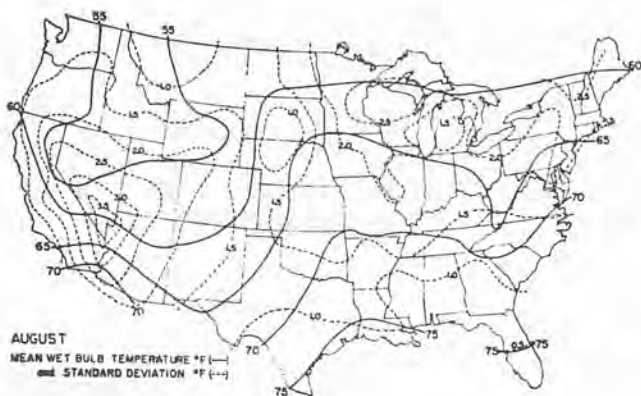
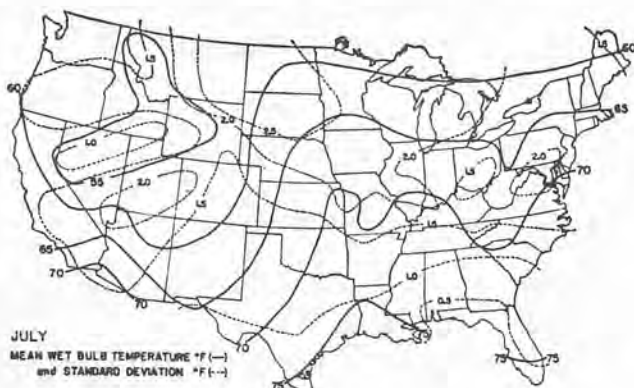
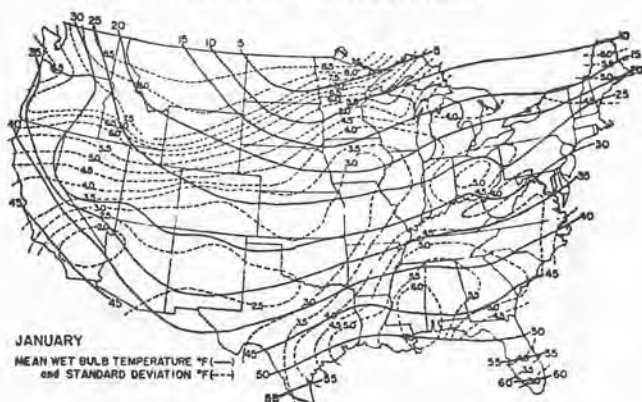
Fig 433-1. Wet-bulb temperatures and wet-bulb depressions.

1.2 In drying high-moisture grain, the temperature of the undried grain approaches the wet-bulb temperature. Higher wet-bulb temperatures shorten permissible drying time. The mean wet-bulb temperature will be lower than the plotted mean temperature in approximately 50% of the years. If one standard deviation is added to the plotted mean, the mean wet-bulb temperature will be lower than the resulting sum in approximately 84% of the years.

ASAE Data: ASAE D309

1.3 In drying high-moisture grain, the rate at which drying can occur is determined in part by the wet-bulb depression. Greater wet-bulb depressions increase drying rates. The mean wet-bulb depression will be greater than the plotted mean depression in approximately 50% of the years. If one standard deviation is subtracted from the plotted mean, the mean wet-bulb depression will be greater than the resulting difference in approximately 84% of the years.

WET-BULB TEMPERATURES



WET-BULB DEPRESSIONS

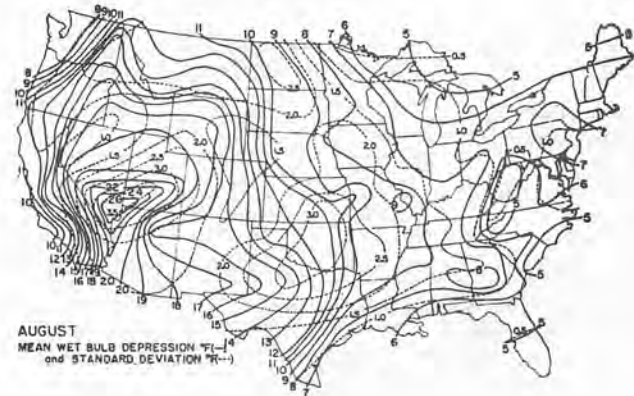
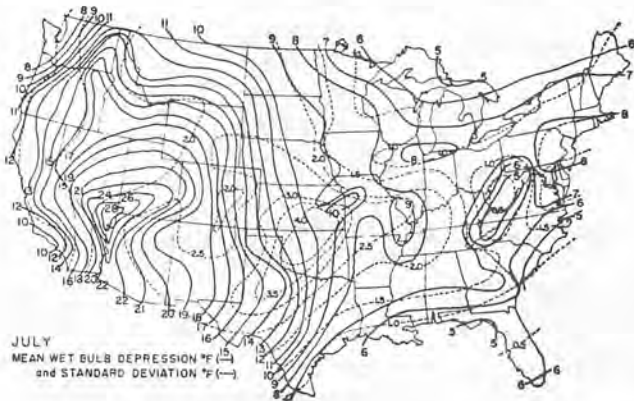
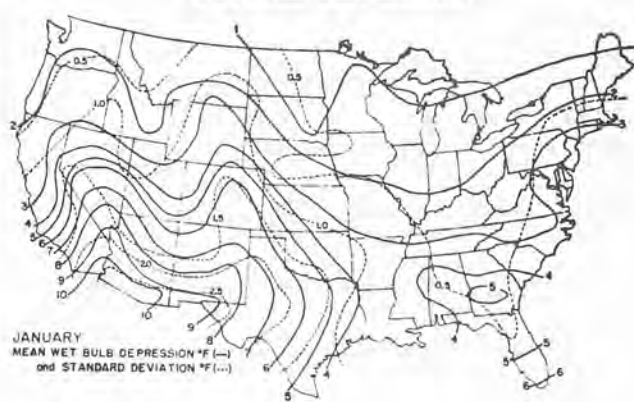
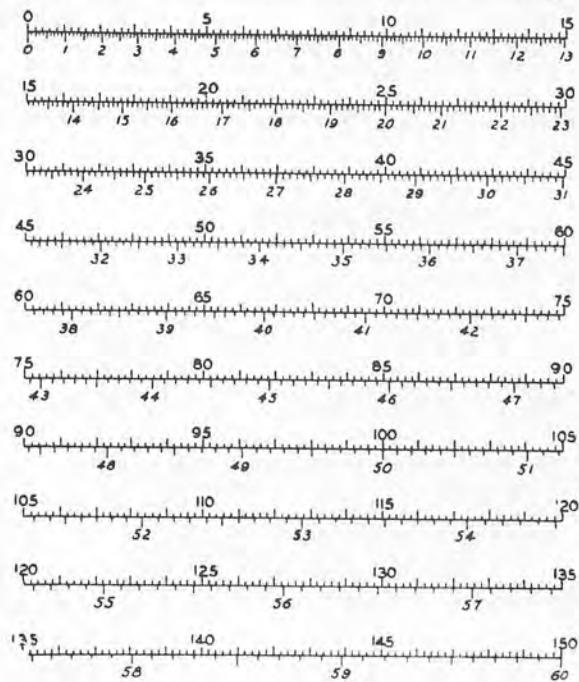


Fig 433-2. Equivalent moisture percentages.

Upper scale: %M_D—moisture content (dry basis) %.Lower scale: %M_W—moisture content (wet basis) %.

$$\text{Conversion equations: } \% M_D = \frac{100 (\% M_W)}{100 - \% M_W}$$

$$\text{and } \% M_W = \frac{100 (\% M_D)}{100 + \% M_D}$$

$$\text{where } \% M_D = \frac{\text{weight of moisture}}{\text{weight of dry material}} \times 100$$

$$\text{and } \% M_W = \frac{\text{weight of moisture}}{\text{weight of wet material}} \times 100$$

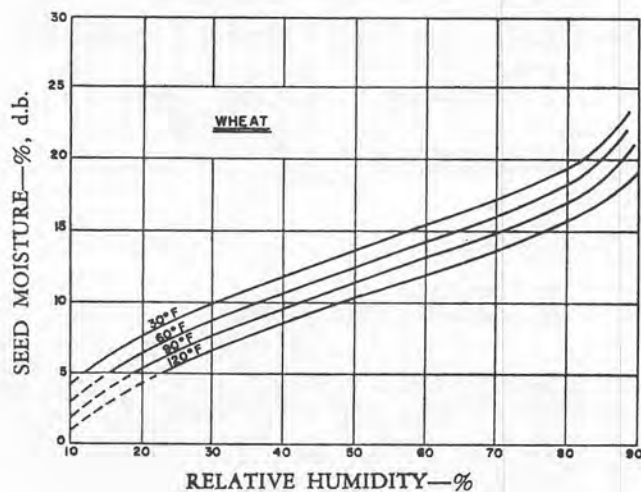
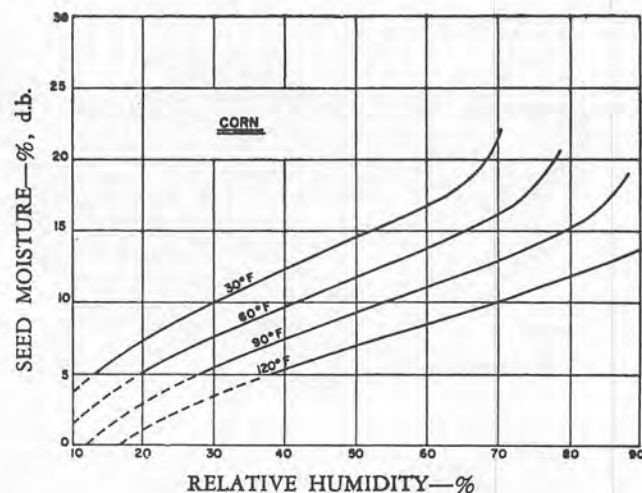
ASAE DATA D245.1

Table 433-1. Lower limit of moisture content, wet weight basis, at which fungi can grow and cause damage in stored grains*. ASAE DATA D244.1

Fungus	Lower moisture content, percent (wet basis)		
	Wheat, barley, oats, corn	Soybeans	Flaxseed
<i>Aspergillus restrictus</i>	13.0-13.5	12.0-12.5	10.0-10.5
<i>A. repens, amstelodami, ruber</i>	13.5-14.0	12.5-13.0	10.5-11.0
<i>A. candidus, ochraceus</i>	15.0-15.5	13.5-14.0	12.0-12.5
<i>A. flavus</i>	17.5-18.0	15.5-16.0	14.5-15.0
<i>Penicillium</i>	16.0-16.5	14.5-15.0	13.0-13.5
<i>Pullularia, yeasts</i>	20.0-21.0	17.0-18.0	15.0-16.0

*These limits apply at temperature range of 5-10C to 30-35C. Growth of these fungi is much slower at 5-10C than at 25-30C.

Fig 433-3. Equilibrium moisture content for corn and wheat.



Extracted with permission from The 1969 Agricultural Engineers Yearbook. The American Society Of Agricultural Engineers, Box 229, St. Joseph, Michigan 49085.

NOTES: This chart gives values for a loose fill (not packed) of clean, relatively dry grain. For a loose fill of clean grain having high moisture content (in equilibrium with relative humidities exceeding 85 percent), use only 80 percent of the indicated pressure drop for a given rate of air flow.

Packing of the grain in a bin may cause 50 percent higher resistance to air flow than the values shown.

When foreign material is mixed with grain no specific correction can be recommended. However, it should be noted that resistance to air flow is increased if the foreign material is finer than the grain, and resistance to air flow is decreased if the foreign material is coarser than the grain.

REFERENCE: Resistance of Grains and Seeds to Air Flow, C. K. Shedd, AGRICULTURAL ENGINEERING, vol. 34, September, 1953.

Fig 433-5. Resistance of shelled corn and wheat to low air flows.

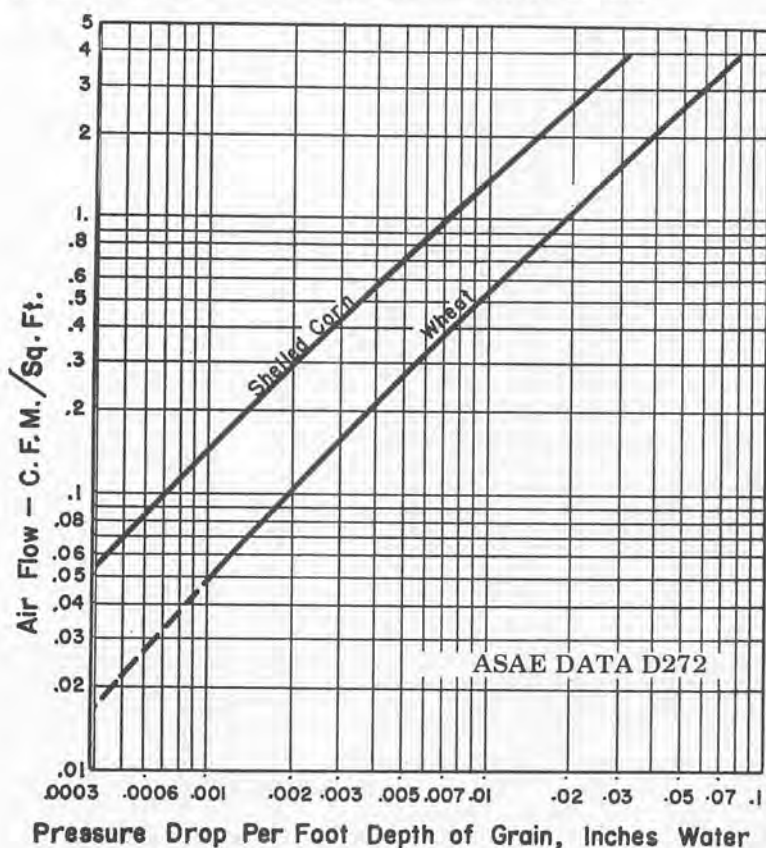
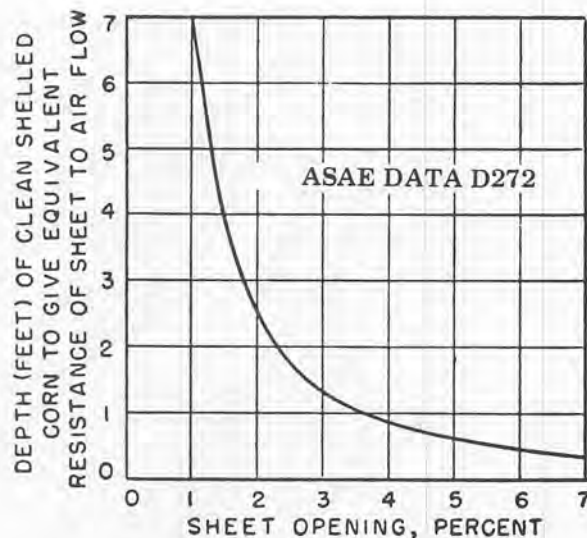


Fig 433-6. Resistance to air flow through perforated metal sheets when supporting grain.



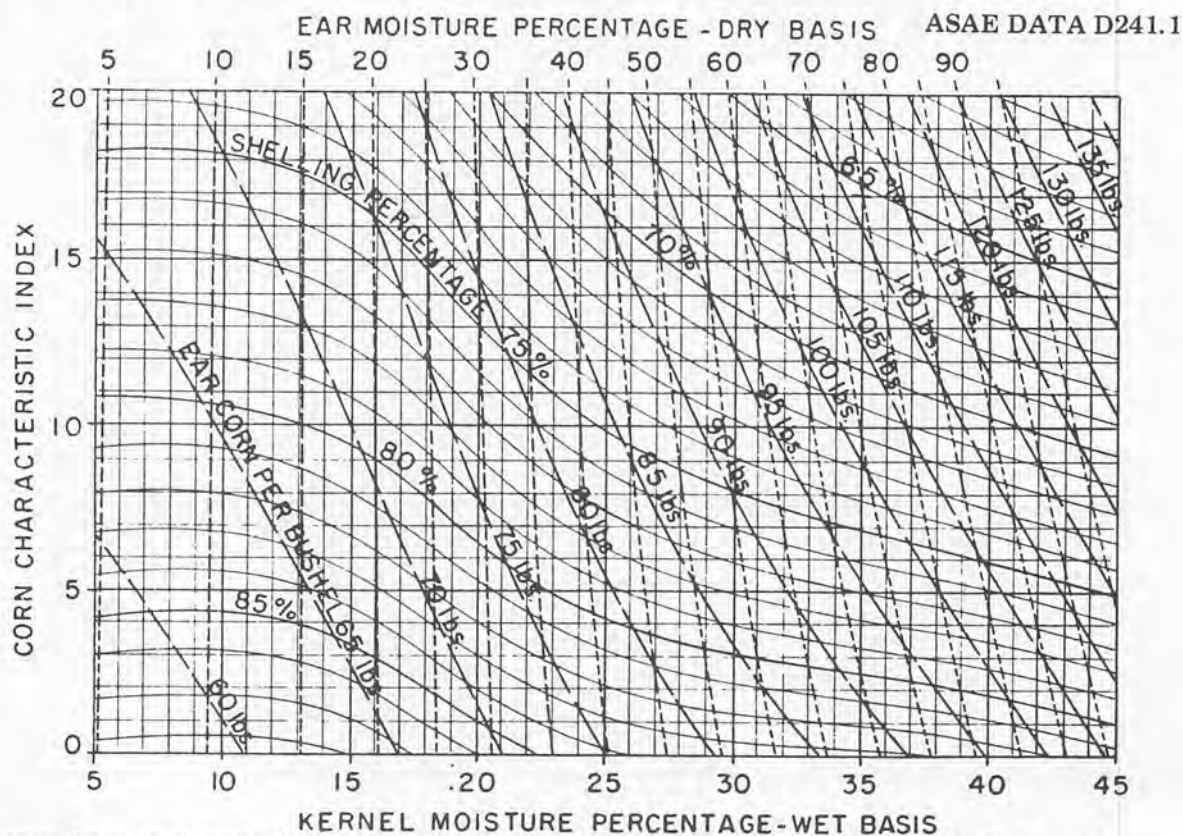
NOTES:

When sheet openings amount to 20 percent, no additional resistance to air flow is produced.

A large number of small perforations is preferred to a smaller number of large perforations for the same amount of opening.

The curve shown is based on tests of sheets having width of perforations from 0.04 to 0.13 in.

Fig 433-7. Relation of kernel moisture content and shelling percentage to total moisture content of ear corn and to pounds of ear corn required to yield one bushel (56 lb) of shelled corn with 15.5 percent moisture content.



NOTE: For any lot of corn the characteristic index number may be determined by measuring kernel moisture and shelling percentage. The corn characteristic index is useful when it is desirable to get successive samples from a field as the corn matures and dries. For a given lot of corn standing in the field the index remains approximately constant as the moisture content drops and other factors change. Once established for a field of corn the index permits making estimates from measurement of kernel moisture only. Corn with a characteristic index of 4 or 5 has well-filled ears. Corn with ears only partly filled or having extensive insect damage will have a higher index number. Fig. 1 of ASAE D241 will apply to corn having a characteristic index of 5 to 7.

Table 433-2. Tables of conveyors.

Type of Conveyor	Type of Material	Capacity	Horsepower Requirement	Cost	Advantages	Disadvantages
SCREW (Auger)	ground granular or chopped	medium	low to medium	medium	1-can be used as mixer or for uniform flow feeder 2-good for unloading bulk storage 3-wide range available	1-size of material limited 2-single sections limited in length 3-medium to heavy wear factor
CHAIN	most feeds grains & farm products	medium	medium	low to medium	1-inexpensive 2-multiple use 3-wide range available	1-noisy 2-heavy wear factor
BUCKET	ground granular or lumpy	medium to high	low	medium to high	1-efficient 2-min.maintenance 3-high capacity for vertical lift	1-limited speed range 2-difficult to erect 3-expensive
BELT	Grain, packaged units	high	low	high	1-can be used for long distances 2-low power requirement	1-limited in angle of elevation 2-expensive
PNEUMATIC	grain ground feed, chopped forage	variable	high	low to medium	1-low first cost 2-low maintenance 3-flexibility of installation 4-easily cleaned	1-high power requirement 2-creates dust, usually requires separation equipment 3-conditions of operation vary with type of material
VIBRATOR	grain ground feed	low	low	high	1-can be used as meter 2-reliable 3-easy control	1-limited capacity 2-cost
OSCILLATOR	grain, feed roughage	high	low	medium to high	1-efficient 2-can handle large volumes 3-can handle several materials	1-cost 2-must be solidly mounted 3-limited to lengths of about 100 ft
PUMP & PIPE	liquids, slurries	high	low	low to medium	1-efficient 2-easy control 3-low maintenance	1-materials limited 2-subject to freezing

Table 433-3. Capacities of auger conveyors.

NOTES: Tables 433-3.

The following five tables are from Research Bulletin No. 740, Purdue University Agricultural Experiment Station.

For all tables:

Horsepower is that required at auger drive shaft. Horsepower loss in drive train must be added to determine the total horsepower requirement of the conveyor. Power loss is generally estimated at 10%, to be added to table values.

To estimate capacities between tabulated values, note that capacity decreases as angle of incline increases. Horsepower increases as angle of incline increases.

Table A. 4" Auger conveyor handling dry shelled corn.*

Auger Speed	Length of Exposed Helix At Intake	Angle of Elevation					
		0°		45°		90°	
RPM	inches	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'
200	6	140	.11	110	.13	40	.10
	12	150	.12	120	.15	60	.11
	18	150	.13	120	.17	70	.12
	24	150	.14	120	.18	80	.13
400	6	270	.23	180	.25	90	.19
	12	290	.29	220	.29	130	.24
	18	290	.33	240	.32	150	.26
	24	300	.38	240	.36	160	.27
700	6	410	.33	280	.40	160	.29
	12	470	.43	350	.52	220	.41
	18	480	.51	380	.64	250	.47
	24	480	.60	380	.76	270	.49
1180	6	490	.41	320	.61	200	.46
	12	650	.63	460	.81	310	.67
	18	740	.85	530	1.01	360	.79
	24	770	1.08	560	1.21	380	.88

* Bushel weight, 54 to 56 lbs; moisture content, 13.2 to 14.2% wet basis.

Table B. 4" Auger conveyor handling dry soybeans.*

Auger Speed	Intake Exposure	Angle of Elevation of Screw									
		0°		22.5°		45°		67.5°		90°	
RPM	inches	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'
300	6	210	.15	180	.21	150	.22	100	.17	80	.17
	12	215	.16	190	.22	160	.24	140	.23	110	.19
	18	220	.21	190	.25	160	.26	150	.25	120	.21
	24	220	.21	190	.26	170	.27	150	.26	130	.24
500	6	330	.23	280	.31	230	.34	170	.32	130	.27
	12	340	.27	300	.39	260	.43	200	.40	160	.33
	18	350	.35	310	.45	270	.47	230	.43	180	.35
	24	360	.38	310	.48	280	.49	250	.46	220	.41
700	6	420	.28	360	.41	290	.45	210	.41	170	.37
	12	450	.37	400	.54	350	.60	270	.57	210	.47
	18	470	.49	410	.63	380	.66	290	.60	240	.49
	24	500	.53	435	.66	380	.71	330	.65	290	.58
900	6	465	.33	400	.49	330	.55	240	.51	200	.45
	12	520	.47	470	.67	410	.74	310	.71	250	.60
	18	570	.62	520	.81	460	.85	350	.77	300	.63
	24	640	.69	550	.87	470	.93	400	.84	350	.73
1100	6	490	.38	420	.56	340	.64	265	.60	220	.55
	12	600	.55	530	.78	460	.86	320	.82	280	.71
	18	690	.77	610	1.00	530	1.03	390	.92	340	.81
	24	780	.84	650	1.06	540	1.14	450	1.01	400	.92

* Bushel weight, 54.5 to 56.0 lbs; moisture content 11.0 to 11.2% wet basis.

Table C. 6" Auger conveyor handling dry shelled corn.*

Auger Speed	Intake Exposure	Angle of Elevation of Screw									
		0°		22.5°		45°		67.5°		90°	
		bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'
200	6	590	.20	520	.30	370	.33	280	.31	220	.25
	12	590	.38	550	.41	500	.44	400	.44	280	.32
	18	620	.32	570	.43	510	.47	430	.45	310	.36
	24	630	.44	590	.50	550	.55	470	.54	350	.40
400	6	970	.35	850	.52	650	.60	480	.57	380	.46
	12	1090	.56	1010	.82	850	.88	690	.83	520	.70
	18	1170	.74	1070	.92	940	1.02	720	.92	560	.80
	24	1190	.97	1110	1.13	1010	1.18	830	1.07	660	.92
600	6	1210	.49	1050	.72	820	.82	590	.77	490	.64
	12	1510	.84	1400	1.22	1160	1.28	910	1.16	740	1.05
	18	1650	1.17	1500	1.42	1270	1.52	1010	1.42	800	1.23
	24	1700	1.47	1570	1.74	1440	1.80	1140	1.60	920	1.40
800	6	1320	.58	1100	.86	890	.95	640	.92	540	.77
	12	1760	1.07	1660	1.54	1370	1.62	1080	1.46	890	1.32
	18	1990	1.57	1790	1.96	1510	2.08	1220	1.94	1000	1.64
	24	2140	1.95	1910	2.32	1740	2.39	1360	2.12	1100	1.89

* Bushel weight, 54 to 56 lbs; moisture content, 14.5% wet basis.

Table D. 6" Auger conveyor handling dry soybeans.*

Auger Speed	Intake Exposure	Angle of Elevation of Screw									
		0°		22.5°		45°		67.5°		90°	
		bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'
200	6	490	.30	410	.41	320	.41	240	.38	180	.34
	12	500	.40	430	.53	360	.57	290	.50	220	.40
	18	520	.50	500	.60	440	.66	360	.60	240	.45
	24	540	.60	520	.67	470	.68	390	.64	290	.52
400	6	880	.52	710	.71	570	.77	400	.70	310	.60
	12	990	.84	830	1.14	690	1.20	540	1.04	390	.79
	18	1110	.98	1030	1.18	880	1.29	740	1.23	460	.95
	24	1180	1.36	1040	1.62	900	1.63	800	1.54	560	1.14
600	6	1080	.68	890	.96	700	1.07	510	1.00	390	.87
	12	1350	1.20	1130	1.61	930	1.71	710	1.48	500	1.10
	18	1620	1.45	1510	1.74	1280	1.94	1070	1.88	660	1.47
	24	1690	2.13	1520	2.52	1320	2.51	1100	2.32	790	1.76
800	6	1180	.78	960	1.12	740	1.28	550	1.22	420	1.10
	12	1610	1.51	1310	1.98	1080	2.10	820	1.84	640	1.50
	18	1980	1.93	1840	2.29	1530	2.54	1230	2.44	810	1.98
	24	2020	2.93	1850	3.43	1640	3.48	1320	3.24	1000	2.56

* Bushel weight, 54 to 56 lbs; moisture content 11 to 12% wet basis.

Table E. 6" Conveyor handling dry, vs handling wet, shelled corn.*

Auger Speed	Corn Moisture	Angle of Elevation of Screw Conveyor									
		0°		22.5°		45°		67.5°		90°	
		bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'	bu/hr	hp/10'
200	14	594	.28	552	.41	498	.44	402	.44	276	.32
	25	372	1.37	318	1.40	282	1.31	204	.97	156	.32
400	14	1086	.56	1008	.82	852	.88	690	.83	516	.70
	25	696	1.84	618	1.89	510	1.78	402	1.45	300	.70
600	14	1512	.84	1404	1.22	1164	1.28	906	1.16	744	1.05
	25	948	2.32	822	2.34	678	2.27	516	1.92	378	1.09
800	14	1764	1.07	1656	1.54	1368	1.62	1080	1.46	888	1.32
	25	1098	2.80	948	2.85	774	2.75	582	2.44	474	1.55

* Moisture contents of 14 and 25% wet basis; 12 inches exposed helix at screw inlet.

Table 433-4. Conveyor capacities.

Table A. Approximate horsepower and capacity for shelled grain belt-type bucket elevators.

Bucket Size	Bucket Spacing inches	Belt Speed ft/min	Capacity bu/hr	Horsepower per 10'
3 x 2	8	270	50	.075
	4		100	
4 x 3	8		200	0.10
	6		300	0.125
6 x 4	4½		500-550	0.20
	4½		700	0.25
7 x 5	8		900	0.30
	6		1200	0.33
9 x 5	7	265	1600	0.5
	6	300	1800	0.5
9 x 6	12	385	1500	0.625
	6	385	3000	1.25

SOURCE: Purdue University, A. E. Data Sheet 8.1

Table B. Belt conveyor capacity guide.*

Belt Width inches	Troughed Belts		Flat Belt	Maximum Speed	
	35 lb/cu ft material	50 lb/cu ft material	50 lb/cu ft material	Fine Grind	Grain
	ton/hr	ton/hr	ton/hr	fpm	fpm
12	8.1	11.5	5.7	300	350
14	11.8	15.8	7.1	300	400
16	14.7	21.0	9.5	300	450
18	18.1	25.9	11.6	400	450
20	23.4	33.4	15.0	400	450
24	34.3	49.0	22.0	500	600

* Uniform Loading -- 100 fpm (feet per minute).

SOURCE: University of California, Agricultural Circular 517.

Table C. Flight conveyor specifications.

Flight Width (in)	HP Required For Various Lengths (ft)								Flight Speed fpm	Approximate Capacities bu/hr
	5-15	16-20	21-25	26-30	31-35	36-40	41-50			
5	1/4-1/3	1/2	3/4	3/4					290-450	300-500
6*	1/4-1/2	1/2-3/4	3/4-1	1					290-450	500-600
8*	1/2-3/4	1/2-1	1/2-1	3/4-1	3/4-1	3/4-1			150-365	400-600
14	3/4	3/4	1	1	1 1/2	1 1/2-3	2		150-225	
18		1/2-1	3/4-1	1-1 1/2	1-2	1 1/2-3	2-5		150	
20			3/4-1	1-2	1-2	1 1/2-3	2-5		150	1200-1400

* Double these hp's for high-capacity bulk feed handling.

Fig 433-8. Estimating weight loss when drying grain or seed.

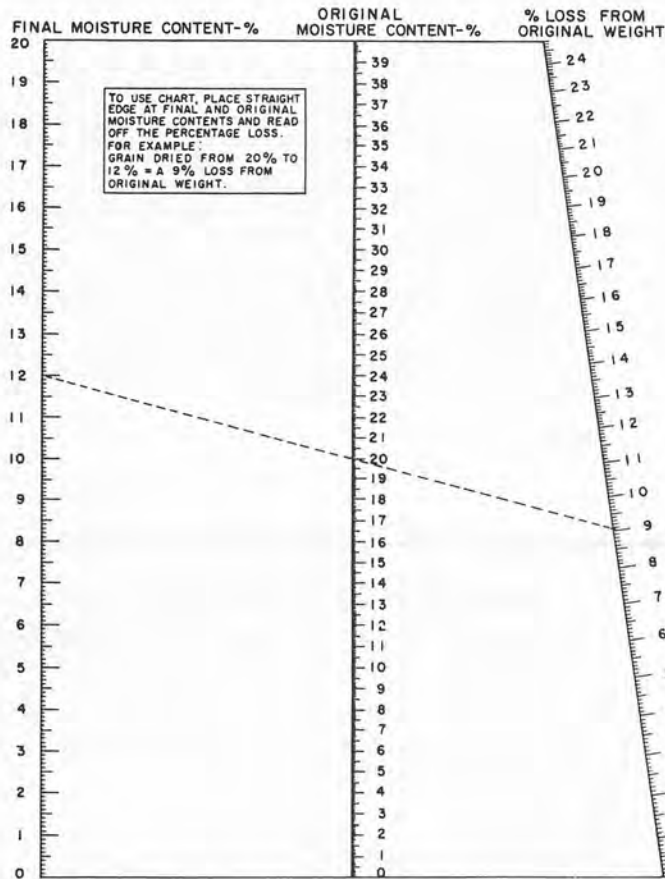


Chart For Estimating Weight Loss When Drying Grain or Seed.

Source: University of Georgia College of Agriculture Bulletin N.S. 33

Table 433-9. Moisture content of grains at harvest and for safe storage in farm-type bins for one year.*

Kind of Grain	At Harvest	For Safe Storage
	P. ct.	P. ct.
Corn (shelled)	14 to 30	Up to 13
Soft Red Winter Wheat	9 to 17	Up to 13-1/2
Oats	10 to 18	Up to 13
Grain Sorghum	10 to 25	Up to 13
Soybeans	9 to 20	Up to 11
Rough Rice	16 to 26	Up to 13-1/2

* For grain stored as seed stock or for long-time storage up to 5 years, the moisture levels should be 2 percent lower for each of the grains.
(Compiled by H. J. Barre, Consulting Agricultural Engineer.)

Table 433-10. Approximate amount of water in ear corn when harvested, at different percentages of moisture content of the kernels.

Kernel Moisture Content (percent)	Amount of Water in a Bushel of Ear Corn ¹		
	In Kernels	In Cobs	Total
	Pounds	Pounds	Pounds
35	25.4	12.4	37.8
30	20.2	9.9	30.1
28	18.4	8.8	27.2
26	16.6	7.8	24.4
24	14.9	6.7	21.6
22	13.3	5.5	18.8
20	11.8	4.4	16.2
18	10.4	3.2	13.6
16	9.0	2.1	11.1
14	7.7	1.4	9.1
12	6.5	0.9	7.4
10	5.3	0.5	5.8

¹ A bushel of ear corn is defined here as the quantity that will yield 56 pounds of shelled corn at 15.5 percent moisture.

SOURCE: USDA MP919

Table 433-8. Approximate storage space requirements for silage and high moisture corn.

Material Description	lb/cu ft	cu ft/ton
Corn shelled:		
25% moisture	43.1	46
30% moisture	39.7	51
Corn and cob meal:		
30% moisture	38.5	52
Silage:		
upright silo	40*	50
horizontal silo	35*	60
spread in bunk	25*	80

* Silage densities and weights are highly variable, depending on material, cut, moisture content and depth in the silo.

Table 433-11. Pounds of water per bushel¹ of grain at different moisture-content percentages²

Grain Moisture content (percent)	Shelled corn and grain sorghum (Pounds of dry matter per bushel = 47.32)	Wheat and soybeans (Pounds of dry matter per bushel = 51.6)	Oats (Pounds of dry matter per bushel = 27.4)
	Pounds	Pounds	Pounds
35	25.4	27.8	14.6
30	20.2	22.1	11.7
28	18.4	20.1	10.6
26	16.6	18.2	9.6
24	14.9	16.4	8.6
22	13.3	14.6	7.7
20	11.8	12.9	6.8
18	10.4	11.4	6.0
16	9.0	9.8	5.2
14	7.7	8.4	4.4
12	6.5	7.0	3.7
10	5.3	5.8	3.0
8	4.1	4.5	2.3

¹ A bushel is defined here as the amount of grain required to yield 56 pounds of shelled corn or grain sorghum at 15.5 percent moisture, 60 pounds of wheat or soybeans at 14 percent, and 32 pounds of oats at 14.5 percent.

² To determine the number of pounds of grain required to make a bushel at a given moisture percentage, add the pounds of water to the pounds of dry matter (shown at head of column). For example: To obtain the weight of corn, at 28-percent moisture content, to make a bushel, add the pounds of water (18.4) to the pounds of dry matter per bushel (47.32). This totals 65.7 pounds. It requires 65.7 pounds of corn at 28-percent moisture content to make a bushel (56 pounds) of 15.5 percent corn.

SOURCE: USDA FB2214

Table 433-12. Storage capacity for common round bins.

Diameter in feet	Bu per foot of height	Capacities for Selected Depths in ft			
		11	13	16	19
14	125	1375	1625	2000	2375
18	203	2200	2635	3250	3850
21	277	3050	3600	4400	5300
24	362	4000	4700	5800	6900
27	458	5050	5950	7300	8700
30	565	6215	7345	9040	10735
36	814	8950	10600	13000	15450
40	1005	11050	13050	16100	19100

* Does not include space above eave line. Based on 15.5 MC corn and 1.25 cu ft per bushel.

Table 433-13. Approximate capacity of ear corn cribs.¹

Rectangular			Round ²		
Width feet	Height feet	Bu per 10 ft Length	Diameter feet	Height feet	Capacity bu
4	12	188	12	12	540
	16	256		16	720
	20	320		20	900
6	12	288	14	12	740
	16	384		16	980
	20	480		20	1230
8	12	384	16	12	960
	16	512		16	1280
	20	638		20	1610
10	12	480	18	12	1220
	16	640		16	1620
	20	800		20	2030

¹ Based on 2½ cubic feet per bushel.

² Includes ½ cone space with no deduction for center tunnel. Roof slope 1:1.

Figuring Grain Storage Capacity

1 bu ear corn = 70 lbs = 2.5 cu ft (15.5% moisture)

1 bu shelled corn = 56 lbs = 1.25 cu ft (15.5% moisture)

1 cu ft = 1/2.50 = 0.4 bu of ear corn

1 cu ft = 1/1.25 = 0.8 bu of shelled corn; bu x 1.25 = ft³; ft³ x 0.8 = bu

Ft³ = bu x 1.25

Bu = ft³ x 0.8

Rectangular or square cribs or bins

cu ft = width x height x length (W x H x L)

Round cribs, bins or silos ($\pi = 3.1416$)

Volume = $\pi R^2 H = \pi D^2 H / 4$

cu ft = $\pi \times \text{radius} \times \text{radius} \times \text{height} = (\pi \times R \times R \times H)$

or $\pi \times \text{diameter} \times \text{diameter} \times \text{height} = \frac{\pi \times D \times D \times H}{4}$

or $\frac{3.1416}{4} \times D \times D \times H = 0.785 \times D \times D \times H$

Examples:

1. Crib - ear corn - 6' wide by 12' high by 40' long

a. $6 \times 12 \times 40 = 2880 \text{ cu ft} \times 0.4 \text{ bu/cu ft} = 1152 \text{ bu}$

b. $6 \times 12 \times 1 = 72 \text{ cu ft} \times 0.4 = 28.8 \text{ bu/ft of length} \times 40' = 1152 \text{ bu}$

2. Round crib - ear corn - 14' diameter by 14' high

a. $.785 \times 14' \times 14' \times 14' \times 0.4 = 861 \text{ bu}$

b. $.785 \times 14' \times 14' \times 1 \times 0.4 = 61.5 \text{ bu/ft} \times 14 = 861 \text{ bu}$

3. Round Bin or Silo - shell corn - 14' diameter by 14' high

a. $.785 \times 14' \times 14' \times 14' \times 0.8 = 1722 \text{ bu}$

b. $.785 \times 14' \times 14' \times 1 \times 0.8 = 123 \text{ bu/ft} \times 14' = 1722 \text{ bu}$

Table 433-14. Approximate storage capacity of round steel bulk feed tanks.

Description	Approximate Overall Height-Feet	Tonnage Capacities Materials Weighing			Approximate Total Capacity cu ft Bu	
		30#/cu ft	40#/cu ft	50#/cu ft		
6' diameter-center draw off,	10 -10½	2.0	2.7	3.4	135	108
60° hopper,	10½-13	3.1	4.2	5.3	210	166
20-24" slide valve clearance	15½-16	4.2	5.7	7.1	285	228
	18 -18½	5.4	7.2	9.0	360	288
	20 -20½	6.2	8.6	10.4	415	322
6' diameter-side draw-off,	14½-15	2.8	3.7	4.7	187	150
60° hopper, 24" slide valve	17 -17½	3.9	5.2	6.6	263	210
	19½-20	5.0	6.7	8.4	338	270
	22½-23	6.1	8.2	10.3	413	330
	25 -25½	7.3	9.7	12.1	487	390
9' diameter-center draw off,	16½-17	8.4	11.2	14.0	561	413
60° hopper, 24" slide valve clearance	19½-20	11.0	14.6	18.3	730	583
	22 -22½	13.5	18.0	22.5	900	720
	24½-25	16.0	21.3	26.7	1067	853
	27½-28	18.6	24.7	30.9	1236	990
12' diameter-center draw off,	20 -20½	16.3	21.7	27.1	1085	870
60° hopper, 24" slide valve clearance	22½-23	20.7	27.7	34.6	1383	1110
	25½-26	25.2	33.6	42.0	1681	1345
	28 -28½	29.7	39.6	49.5	1980	1585
	30 -30½	34.2	45.6	57.0	2278	1820
	33 -33½	38.7	51.5	64.4	2577	2060
	36 -36½	43.1	57.5	71.9	2875	2300
	38½-39	47.6	63.5	79.3	3174	2540
	41½-42	52.0	69.4	86.8	2472	2780

Table 433-15. Rate of harvesting corn. *

Machine	Acres/Hr	Bushels Harvesting at Yield of		
		75 bu/A	100 bu/A	125 bu/A
One-row picker	.6 to .7	50	65	75
Two-row picker	1.1 to 1.3	95	120	140
Two-row picker sheller	1.1 to 1.4	105	125	145
Two-row combine	1.2 to 1.4	110	135	140
Four-row combine	2.3 to 2.6	200	240	275

* Allows for down time for changing wagons, unloading bins, major adjustments and turning, and reasonable driving speed to minimize field losses.

The rate of harvest will vary with field conditions, moisture content of corn harvested and yield per acre.

SOURCE: Robert G. White, Michigan State University

Table 433-16. Size and spacing of hoop reinforcing rods for concrete stave bins for dry grain.

Distance From Top in Feet	Diameter of Bin					
	10, 12 and 14 ft	16 ft	18 ft	20 ft	25 ft	30 ft
0-10	15"	15"	15"	15"	5/8" Diameter	11/16" Diameter
10-15	15	15	15	15	15"	15"
15-20	15	15	10	10	15	10
20-25	15"	15"	10"	10"	10"	10"
25-30	15"	10"	10"	10"	11/16" Diameter	10"
30-35	15	10	10	7½	10"	7½
35-40	15"	10"	10"	7½"	7½"	7½"
40-45	15	10	10	7½	7½	7½
45-50	15	10	10	7½	7½	7½

CHAPTER 434 SILO CAPACITIES AND FEED DATA

Determining Silo Size*

The capacity of a silo depends mainly on its height and diameter.

Other factors are moisture content of crop when ensiled, length of cut, rate and distribution of filling, amount of grain in corn silage, and maturity of crop. So it is impossible to provide an accurate table.

Of these other factors, crop moisture content is the most important; but, the capacity of the silo on a dry matter basis is reasonably consistent within the range of 50%-70% moisture.

Required Silo Size

Height:

Amount removed, feet/day

Weather

	cold	warm
Whole corn	1/6'	1/3'-1/2'
Alfalfa-brome	1/6'	1/4'-1/3'
Chopped ear corn	1/6'	1/6'
Cracked shelled corn	1/3'	1/3'

Times the number of days in the feeding period,

Equals the height of settled silage.

Allow at least 10' of extra height for settling and for storage of silo unloader.

Therefore: height = feet/day x days + 10'

Diameter:

Dry Matter fed per day,

Times the days in the feeding period,

Divided by 2000,

Equals total tons needed.

Use total tons, and depth of settled silage in the Table 434-9 to determine diameter.

Therefore: tons = lbs dry matter/day x days ÷ 2000

and: diameter selected from Table 434-9 using height and tons.

To convert tons (or pounds) of dry matter to tons (or pounds) of silage, estimate % moisture of silage and multiply weight by the factor below:

% moisture of silage:	40%	45%	50%	55%	60%	65%	70%
Multiply weight of dry matter by:	1.6	1.8	2.0	2.2	2.5	2.8	3.3

Grass or corn silage is commonly stored at about 65% moisture, and haylage at about 50%.

Table 434-1. Dry Matter to be stored per animal unit.

If 40% of dry matter comes from concentrates during high production (about 1 lb grain to 3 lb milk). Allows for storage loss, normal feeding waste, and if concentrates supply 50% of the dry matter, decrease the roughage by 10%. If concentrates provide 30% of the dry matter, increase roughage by 10%.

Pounds of dry matter per day

Weight of Cow (lb)	2/3 Hay		1/2 Hay		1/3 Hay		Hay, or Silage
	1/3 Silage		1/2 Silage		2/3 Silage		
	Hay	Silage	Hay	Silage	Hay	Silage	
800	9.7	4.9	7.3	7.3	4.9	9.7	14.6
1000	12.2	6.1	9.1	9.2	6.1	12.2	18.3
1200	14.7	7.3	11.0	11.0	7.3	14.7	22.0
1400	17.1	8.5	12.8	12.8	8.5	17.1	25.6
1600	19.5	9.7	14.6	14.6	9.7	19.5	29.2

Tons of dry matter per year

Weight of Cow (lb)	2/3 Hay		1/2 Hay		1/3 Hay		Hay, or Silage
	1/2 Silage		1/2 Silage		2/3 Silage		
	Hay	Silage	Hay	Silage	Hay	Silage	
800	1.8	.9	1.3	1.3	.9	1.8	2.7
1000	2.2	1.1	1.7	1.7	1.1	2.2	3.3
1200	2.7	1.3	2.0	2.0	1.2	2.7	4.0
1400	3.1	1.6	2.3	2.3	1.3	2.7	4.0
1600	3.6	1.8	2.7	2.7	1.8	3.6	5.3

*From "Determining Silo Size and Location", Berge et al, U. of Wisconsin

Table 434-2. Pounds of roughage consumed per day; dry matter consumption=3% of body weight.

Weight of Cows	Hay Only	2/3 Hay	1/2 Hay	1/3 Hay	All Silage	2/3 Silage	1/2 Silage	1/3 Silage
Medium Concentrate Levels:								
1000	24.8	16.5	12.4	8.3	74.4	49.5	37.2	24.9
1200	29.7	19.8	14.9	9.9	89.1	59.4	44.7	29.7
1400	34.7	23.1	17.4	11.6	104.1	69.3	52.2	34.8
1600	39.6	26.4	19.8	13.2	118.8	79.2	59.4	39.6
1800	44.6	29.7	22.3	14.9	133.8	89.1	66.9	44.7
High Concentrate Levels:								
1000	16.5	11.0	8.3	5.5	49.5	33.0	24.9	16.5
1200	19.8	13.2	9.9	6.6	59.4	39.6	29.7	19.8
1400	23.1	15.4	11.6	7.7	69.3	46.2	34.8	23.1
1600	26.4	17.6	13.2	8.8	79.2	52.8	39.6	26.4
1800	29.7	19.8	14.9	9.9	89.1	59.4	44.7	29.7

To convert hay to haylage, multiply hay by 2.

Table 434-3. Tons of forage consumed in 365 days.

Weight of Cows	Hay Only	2/3 Hay	1/2 Hay	1/3 Hay	All Silage	2/3 Silage	1/2 Silage	1/3 Silage
Medium Concentrate Levels:								
1000	4.5	3.0	2.3	1.5	13.6	9.1	6.8	4.5
1200	5.3	3.6	2.7	1.9	16.4	10.9	8.1	5.3
1400	6.4	4.3	3.2	2.1	19.1	12.7	9.6	6.4
1600	7.2	4.8	3.6	2.4	21.8	14.6	10.9	7.2
1800	8.1	5.5	4.1	2.7	24.6	16.4	12.3	8.1
High Concentrate Levels:								
1000	3.1	2.0	1.5	1.6	9.1	6.0	4.5	3.1
1200	3.6	2.4	1.9	1.2	10.9	7.2	5.5	3.6
1400	4.3	2.8	2.1	1.5	12.7	8.5	6.4	4.3
1600	4.8	3.2	2.4	1.6	14.6	9.7	7.2	4.8
1800	5.5	3.6	2.7	1.9	16.4	10.9	8.1	5.5

To convert hay to haylage, multiply hay by 2.

Table 434-4. Pounds of dry matter in 2" layers of tower silos of different diameters.

Silo Diameter feet	Pounds Dry Matter* in 2" layers
12'	282
14	384
16	502
18	636
20	785
22'	950
24	1131
26	1329
28	1539
30	1767

*Assuming 15 lb dry matter/cu ft.

Table 434-5. Maximum exposed surface area for horizontal silos to remove 4" vertical slice per day.

Feeding Rate lb per cow	Square Feet per cow
20	2
30	3
40	4
50	5
60	6
70	7
80	8

Table 434-6. Number of cows fed per 2" layer of corn silage at various feeding rates.

Silo Diam. ft	Pounds of Silage Per Day Per Animal						
	20	30	40	50	60	70	80
Number of animals to consume 2" layer at above rate							
18	106	71	53	42	35	30	28
20	131	87	65	52	43	37	33
22	158	105	79	63	53	45	39
24	188	126	94	75	63	54	47
26	222	144	111	88	74	63	56
28	256	171	128	103	86	73	64
30	295	196	147	118	98	84	74
32	335	223	168	134	113	96	84
34	379	252	189	151	126	108	95
36	424	283	212	169	141	121	106

Table 434-7. Capacities of horizontal silos per 10 feet of length (level full at 50 cu ft=1 ton)

Depth	Silo Floor Width									Closed End Ratio
	20	30	40	50	60	70	80	90	100	
10 bu tons	1800 45	2600 65	3400 85	4200 105	5000 125	5800 145	6600 165	7400 185	8200 205	1/8
12 bu tons	2208 55	3168 79	4128 103	5088 127	6048 151	7008 175	7968 199	8928 223	9888 247	1/7
14 bu tons	2632 66	3752 94	4872 122	5992 150	7112 178	8232 206	9352 234	10472 262	11592 290	1/6
16 bu tons	3064 77	4344 109	5624 141	6904 173	8184 205	9464 237	10744 269	12024 301	13304 333	1/5
18 bu tons	3528 88	4968 124	6408 160	7848 196	9288 232	10728 268	12168 304	13608 340	14048 376	1/5
20 bu tons	4000 100	5600 140	7200 180	8800 220	10400 260	12000 300	13600 340	15200 380	16800 420	1/4

Example: 50' wide, 12' deep, 120' long, 1 end closed.

Capacity per 10', from table = 127 tons

Capacity per 120' = 12 x 127 = 1524 tons
Closed end holds additional silage.

Multiply closed end ratio for silage depth times the capacity / 10':

$1/7 \times 127 = 18$ (about)

Open end will be less than full. Deduct for capacity lost:

Slope of Silage	Deduction
1/4	closed end capacity
1/2	2 x " " "
1/1	4 x " " "

Assume slope of 1/2

closed end capacity = 18 tons

deduct 2 x 18 = 36 tons

Total capacity = 1544 + 18 - 36 = 1526 tons.

Table 434-8. Spacing of reinforcing rods for storing legume and grass silage and high moisture shelled corn in concrete stave and cast-in place silos.

Diameter	10'0"		12'0"		14'0"		16'0"		18'0"		20'0"	
Silo Type ¹	S	C-P	S	C-P	S	C-P	S	C-P	S	C-P	S	C-P
Rod Diameter	9/16"	1/2"	9/16"	1/2"	9/16"	1/2"	9/16"	5/8"	9/16"	5/8"	9/16"	5/8"
Distance From Top in Feet	Spacing of Horizontal Rods, in Inches											
0-5	30	24	30	24	30	24	30	24	30	24	30	24
5-10	30	24	30	24	30	24	30	24	15	24	15	24
10-15	30	24	15	24	15	20	15	24	15	24	15	22
15-20	15	22	15	18	15	15	15	20	10	18	10	16
20-25	15	17	15	14	15	12	10	17	10	15	10	13
25-30	15	14	15	12	10	10	10	14	10	12	7½	11
30-35	15	12	10	10	10	9	10	12	7½	11	7½	9
35-40	10	10	10	9	7½	8	7½	10	7½	9	6	8
40-45			10	8	7½	7	7½	9	6	8	6	7
45-50			7½	7	7½	6	6	8	6	7	6½	6
50-55					6	5	6	7	5	6	6½	6
55-60					6	5	7	7	5	6	5½	5

¹ S = Stave Silo, Round Rods -- Rolled Threads -- Galvanized

C-P = Cast-In-Place Silo, 2 foot rod overlap at splices, 6 inch wall thickness, reinforcing rods centered in wall. Additional vertical steel is needed for all silo sizes: 3/8" round bars 30" apart.

² 5/8" diameter rod.

If the reinforcing in your silo is not exposed and you cannot find out what it is, it would be wise to add reinforcing bands on the outside in accordance with the recommendations in the table.

SOURCE: "Building and Remodeling Silos for Legumes and Grass Silage," Concrete Information, No FB-7, Farm Bureau, Portland Cement Association, Chicago 1954.

Table 434-9. Approximate dry matter capacity of silos.

Depth of Settled Silage, ft	Silo Diameter, ft										
	10'	12'	14'	16'	18'	20'	22'	24'	26'	28'	30'
	TONS of dry matter										
20'	8	12	16	21	27	33	40	47	56	65	74
22	9	14	19	24	30	38	48	54	64	74	85
24	11	15	21	27	34	43	52	61	72	83	96
26	12	17	23	30	38	48	58	68	81	94	107
28	13	19	26	35	44	53	64	76	90	104	119
30	15	21	29	38	47	59	71	84	99	115	132
32'	16	23	32	41	52	65	78	93	109	127	145
34	18	25	34	45	57	70	85	101	119	137	158
36	19	28	37	48	62	76	92	109	129	150	172
38	21	30	41	53	67	82	100	118	139	161	185
40	22	32	44	57	72	89	107	127	150	173	199
42'		34	47	61	77	95	115	137	161	186	214
44		37	50	65	82	102	123	146	172	200	229
46		39	53	69	88	108	131	155	183	212	244
48		42	56	74	93	115	140	166	195	226	260
50		44	60	78	99	122	148	175	206	239	274
52'			64	83	105	129	157	186	219	254	291
54			67	88	111	137	165	197	231	267	306
56			71	93	117	144	174	207	243	282	324
58			74	98	123	151	183	218	261	297	339
60			78	102	129	159	192	228	273	309	357
62'					135	167	201	239	287	324	374
64					142	174	210	250	301	339	391
66					149	182	219	260	314	354	407
68					155	190	228	271	328	369	424
70					162	198	237	282	342	384	441
72'								293	356	400	458
74								305	371	415	476
76								316	385	431	493
78								328	400	446	511
80								339	414	462	528

To estimate tons of silage of various moisture contents multiply Tons of dry matter
 100

x $\frac{\text{estimated \% dry matter in silage}}{100}$ = tons actual silage.

CHAPTER 435 MATERIALS AND STORAGE

Fig 435-1. Bedding materials—approximate water-absorbing capacity.

lbs of water/lb of bedding	
	WOOD
4.0	Tanning bark
2.5	Dry fine bark
3.0	Pine chips
2.5	sawdust
2.0	shavings
1.0	needles
1.5	Hardwood chips, shavings or sawdust
	CORN
2.5	Shredded stover
2.1	Ground cobs
	STRAW
2.6	Flax
2.8	Oats, threshed
2.5	combined
2.4	chopped
2.2	Wheat, combined
2.1	chopped
3.0	HAY, chopped mature
	SHELLS, HULLS
2.7	Cocoa
2.5	Peanut, cottonseed
2.0	Oats

Table 435-3. Capacities of hay sheds with 20' sidewalls.

Shed Width	Capacity per foot of Length tons		
	Baled	Chopped	Loose
24'	2.0	1.9	0.8
30'	2.6	2.3	1.0
36'	3.1	2.8	1.2
40'	3.4	3.1	1.4

Table 435-2. Storage space requirements for feed and bedding.

CROP	Lbs/Bu	Lbs/Cu Ft	Freshly Ground		HAY-STRAW	Cu Ft/Ton	Lb/Cu Ft
			Lbs/Bu	Lbs/Cu Ft			
corn 15½% shelled ear	56 70	44.8 28.0	48 45	38 36	Alfalfa Non legume	450-500 450-600	4.4-4 4.4-3.3
corn 30% shelled ear, ground	(Amounts to yield a bu or c ft of 15½% grain.) 67.5	54.0			Straw	670-1000	3-2
barley 15% flax 11% grain sorghum 15% oats 16% rye 16% soybeans 14% wheat 14%	48 56 56 32 56 60 60	38.4 44.8 44.8 25.6 44.8 48.0 48.0	89.6 37 23 48 50	35.8 28 18 38 43	Alfalfa Non legume Straw Alfalfa Non legume Straw	200-330 250-330 400-500 CUT 1½" 3 " 285-360 300-400 250-350	10-6 8-6 5-4 CHOPPED 7-5.5 6.7-5 8-5.7

440 UTILITIES

CHAPTER 441 WATER SUPPLY

Sources

A water supply may be obtained from either surface or underground sources. Surface water is in lakes, streams, and drainage areas that funnel water toward holding reservoirs, and surface depressions that capture and hold rain water. Ground water is in water-yielding geologic formations, called aquifers, beneath the earth's surface.

Ground water

Ground water is usually the safest and most reliable source of water. However, some shallow water-table wells and springs are easily contaminated and also may go dry in drought periods.

Artesian wells are less subject to contamination than water-table wells, because the upper confining bed restricts the movement of contaminants into the artesian aquifer. See Fig 441-1.

State water agencies can usually provide information on the availability of ground water in your area.

Surface water

Stream and lake water is usually contaminated. It is not recommended for domestic use in private water systems without extensive treatment.

Caution. Check state codes before using any surface water for a domestic supply. Some states prohibit the use of surface water for this purpose.

Surface water collected in farm ponds is usually suitable for livestock and for fighting fires, but should be considered for home and milkhouse use only when ground water sources are inadequate or prohibitive in cost. Surface water used in the home and milkhouse must always be filtered and disinfected.

Surface water collected in cisterns, reservoirs and other man-made storages is often used to supplement ground water sources, and for emergencies such as fires. Some water systems are designed to have these storages supply all water needs. If this collected water will be used in the home and milkhouse, the storages must be carefully constructed and protected from additional contamination.

Quantity

A correctly designed water system will supply the quantity of water needed every day throughout the year. In addition, it will deliver water at a rate that will meet the temporary large demands that occur each day. It will also provide enough water to fight small fires.

Requirements

Water systems must meet the requirements of many simultaneous activities during short periods of time.

The flow rate during peak use periods is called the peak use rate. The water system in a home should be capable of supplying the peak use rate continuously for 1 hour.

Common household planning provides 50 gallons per day per person, of which one-third to one-half is for flushing toilets. Peak daily use may reach 100 gallons per day per person.

If the peak use rate exceeds the maximum well yield, intermediate storage should be installed to help supply water during peak use periods.

Peak use rates determine pump capacity, pipe size, temporary storage capacity and other water system features. Average year-round water use rates determine long time storage capacity where the water source is a pond or cistern.

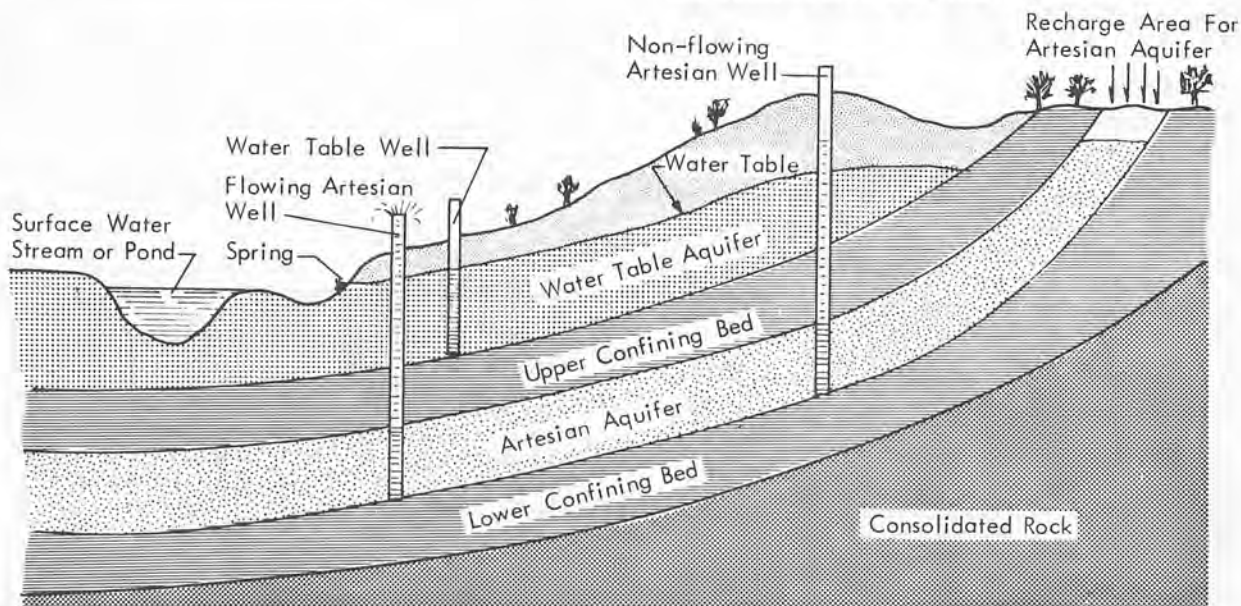


Fig 441-1. Ground and surface water sources.

Table 441-1. Safety characteristics of water sources.

Source	Primary Uses	Safety	Treatment* Usually Recommended to Make Water Safe for DOMESTIC Use
Drilled well	Domestic and livestock	Usually best of all sources on the farm	None, unless subject to contamination
Dug, jetted, driven, or bored	Domestic and livestock	Subject to contamination	Automatic chlorination
Spring	Livestock and domestic	Subject to contamination	Automatic chlorination
Cistern (untreated water)	Domestic and fire protection	Subject to contamination from roof runoff	Automatic chlorination and filtration
Farm pond	Livestock and fire protection	Subject to contamination	Automatic chlorination and filtration
Stream or lake	Livestock	Subject to contamination	Stream not recommended for domestic use without extensive treatment
Controlled catchment	Livestock and domestic	Subject to contamination	Automatic chlorination and filtration
Hauled water	Domestic	Good if hauled from safe source in safe containers	None if safely stored, but chlorination is desirable

*Additional treatment may be needed to remove undesirable minerals.

The water system for a farm or farmstead should supply the peak use rate continuously for 2 hours. For larger farm enterprises with high capital investment, it may be desirable to provide at least 20 gallons per minute (gpm) at 60 pounds per square inch (psi) for fire control.

Water system flow rate

The water system flow rate, in gallons per minute, should at least equal the peak use rate. Estimate the peak use rate as follows:

Home water system

The minimum flow rate for any home should be 6 gpm; 10 gpm is more desirable. However, to prevent undersizing, the flow rate should never be less than the peak demand of the largest single fixture. For example, a flow rate of 20 gpm is needed to properly backwash some kinds of water filters. Future water requirements should be estimated so that an adequate flow rate will be available when needed. See Tables 441-2 and 441-3.

Table 441-2. Flow rates for home water systems.

No. of Bedrooms	Flow Rate in gpm in Relation to Number of Bathrooms in Home			
	1 Bath	1½ Bath	2 Bath	3 Bath
2 Bedroom	6 gpm	8 gpm	10 gpm	--
3	8	10	12	--
4	10	12	14	16 gpm
5	--	13	15	17
6	--	--	16	18

Table 441-3. Home and outdoor living water requirements.

Use	Flow Rate in gpm	Total Use in Gallons
Automatic washer	5	30- 50/load
Non-automatic washer or laundry tub	5	15- 45/load
Dishwasher	2	7- 15/load
Garbage disposer	3	4- 6/day
Kitchen sink	3	2- 4 each use
Shower or tub	5	25- 60 each use
Toilet-flush	3	4- 7 each use
Bathroom lavatory	2	1- 2 each use
¹ Water softener regeneration	8	50-150 each time
Backwash filters	15	100-300 each backwashing
Outside hose faucet	5	---
² Swimming pool	-	---
³ Fire protection	10	1200/2 hours

¹ The size and type of softener and filter affect water flow rate and quantity required for backwashing and regeneration. Determine these for each specific use.

² The size and type of swimming pool affects the amount of water needed to fill the pool and also the water needed to keep the pool clean and usable. Each owner must determine the water needed for his specific pool.

³ For do-it-yourself fire fighting, a minimum of 10 gpm with a 1/4-inch nozzle at 30 psi for 2 hours is recommended.

Farmstead water system

Where water for livestock production is supplied through the same system as water for the home, the flow rate must be increased to meet those needs. The minimum flow rate for a farmstead should be 8 gpm; 10 gpm is more desirable.

Flow rates for various types of water-using equipment are given in Table 441-4, Farm Water Requirements. The farmstead flow rate is the sum of those flow rates for all equipment that will be in use at one time, added to the flow rate for the farm home.

Example: (for 600 market hog production unit plus farm family):

10 automatic waterers, 2 watering spaces	
per waterer	@ 1 gpm = 10 gpm
1 hose for hydraulic waste removal	@ 10 gpm = 10 gpm
Flow rate for livestock production	= 20 gpm
Flow rate for farm home (4 br, 2 baths)	= 14 gpm
Flow rate for farmstead	34 gpm

The minimum pressure at any outlet should be 10 psi. Some fixtures require at least 15 psi to operate properly. A listing of recommended fixture pressures is in Table 441-5.

Table 441-5. Recommended minimum water pressure at typical outlets.

Outlet	Pressure
Lavatory, sink or bathtub	10 psi
Shower	12
Tank toilet	15
Flush-valve toilet	20
Hose faucet	20
Hose faucet for fire control	30
Livestock waterer	15

Table 441-4. Farm water requirements.

	Gallons per Day		Additional Water Needs
	Air Temperature 50°F ²	90°F ³	
Cattle: dry cow, bull, steer, calf (per 1000 lbs live weight)	9 gpd	18 gpd	
Milk cow (per 1000 lbs live weight)	6	9	
+ additional water (per lb of milk produced)			1/3 gpd ⁴
+ additional for milkhous and barn sanitation (per milk cow)			10 to 30 ⁴
Horse or mule (per 1000 lbs live weight)	8	12	
Swine, sow, boar, market hog (per 100 lbs live weight)	1	1 1/2	
Sheep, ewe, ram, market lamb (per 100 lbs live weight)	1	1 1/2	
Chickens (per 100 layers)	6	9	
Turkeys (per 100 head)	10	15	
For each:	Gallons per Minute		
	Minimum	Preferred	
Automatic cattle, hog or sheep waterer (20 to 40 head per watering space or bowl)	1/2 gpm	2 gpm	
Automatic poultry fountain (100 to 150 layers per fountain)	1/4	1	
Dairy utensil cleaning and milkhous sanitation hose	3	5	
Sanitation and hydraulic waste removal hose in milking barn or hog house	5	10	
Outdoor hydrant for uses other than fire fighting	3	5	
Fire hydrant ⁵	10	50	

¹Water consumption is affected by air temperature, size of animal, species, age, amount of milk or egg production, type of ration, amount of dry matter consumed and other variables. These are average values for two air temperatures.

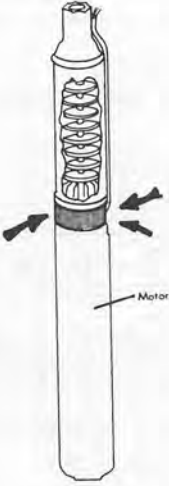
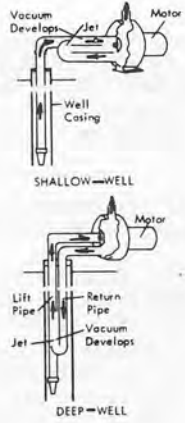
²Average water consumption when air temperature around animals is about 50°F. Use values in this column to figure pond storage requirements if average year-round temperature is about 50°F.

³Use values in this column, or adjusted values according to the maximum air temperatures expected in your area, to figure daily peak use rate that a pump must supply.

⁴Amount of water used for cow washing, milk cooling, utensil cleaning, waste flushing and general sanitation varies widely from one farm to another.

⁵From a 1/4-inch nozzle at 30 psi to a 1/2-inch nozzle at 50 psi.

Table 441-6. Pump characteristics.

	SUBMERSIBLE Multistage	JET (or EJECTOR) Shallow-Well or Deep Well	CENTRIFUGAL Shallow-Well
Practical Lift	To 1,000 feet	To 22 feet for shallow-well jet and to 85 feet for deep-well jet. Greater depths are possible for deep-well jet, but at the price of reduced efficiency.	To 15 feet.
How It Works	Operates the same as a shallow-well centrifugal pump except there are several impellers mounted close together on a single shaft. The impellers, along with the motor, are placed within a watertight housing immersed in the water source. Each impeller and its diffuser (a guide to the next impeller) is called a stage. Submersible pumps usually require a 4" or larger casing.	Jet pumps consist of a pump (usually centrifugal) and a jet or ejector assembly. The assembly is installed within the pump for shallow-well units, or is installed down in the well to make a deep well unit. The assembly consists of a body, a nozzle and a venturi tube or throat. The pump forces some water through the nozzle and venturi tube and forces the rest of the water to the distribution system.	A rotating wheel or impeller develops a vacuum in the intake pipe. Water fills the vacuum and the impeller increases the velocity of the water and forces it into a surrounding casing shaped to slow down the flow and convert the velocity to pressure.
Advantages	Produces a smooth and even flow. Easy to frost-proof installation. Short pump shaft to motor.	Few moving parts. Both shallow-well and deep-well jets can be offset from the well. High capacity at low heads. Can be offset from the well.	Produces a smooth, even flow. The open impeller, but not the closed impeller, type. Will pump water containing small amounts of sand. Usually reliable and has a good service life.
Disadvantages	Repair to pump or motor requires pulling from well. Easily damaged by sandy water.	Easily damaged by sandy water. The amount of water returned to ejector increases with increased lift; 50% of the total water pumped at 50 feet lift, and 75% at 100 feet lift.	Loses prime easily. Efficiency depends on operating under design heads and speed.
Remarks	These pumps usually operate at 3500 rpm, the fastest practical speed for a 60-cycle electric motor. Pump capacity depends on the design of the impeller. The pressure depends on the diameter, speed and number of impellers.	Capacity depends on the design and number of impellers in the jet. The pressure depends on the diameter, speed, and number of impellers.	Very efficient for capacities over 50 gallons per minute and pressures less than 65 pounds per square inch. An ideal pump for use as a booster pump; can be offset from the water source.
			

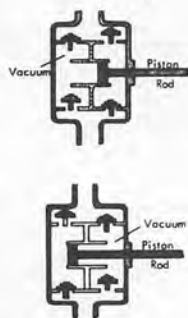
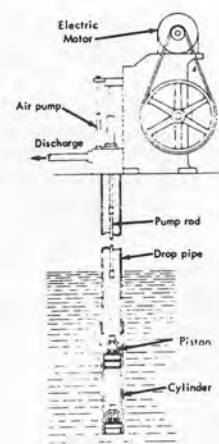
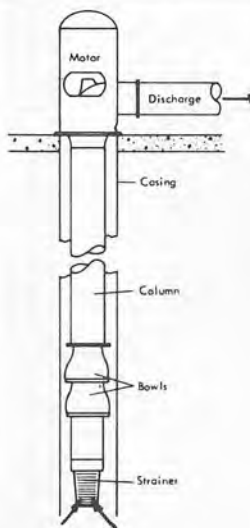
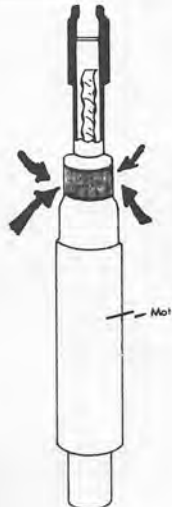
RECIPROCATING OR PISTON		DEEP WELL TURBINE	SUBMERSIBLE
Shallow Well	Deep Well	Multistage	Helical Rotor
To 22 feet.	To 600 feet.	To 1,500 feet.	To 1,000 feet
A piston is driven within a chamber and develops a vacuum. Water fills the vacuum and is forced into the water system as the piston reverses direction.	A pump cylinder is attached to the bottom of the drop pipe. A piston is attached to a rod in the drop pipe. As the piston is forced up and down it pumps water up through the drop.	Operates the same as a centrifugal pump except that there are one or more impellers mounted close together on a vertical shaft. The bowls (each bowl is one stage—an impeller and its diffuser) are placed below the pumping water level with the column (discharge pipe) and shaft extending to the surface.	A positive displacement pump mounted with a motor in a water-tight housing.
Can pump water containing small amounts of sand. Can be installed over small diameter wells. Positive displacement which means a constant rate of yield. Adaptable to hand operation.	Same as for shallow-well. The open-type cylinder is easy to maintain.	Produces a smooth and even flow. Easy to frost-proof installation. Long drive shaft requires installation in a straight and vertical well casing.	Produces a smooth and even flow. Easy to frost-proof. Short pump shaft to motor. Will pump sand with less pump damage than any other type.
Pulsating discharge, and may cause vibration and noise.	Same as shallow-well and the pump must be set directly over the well.	Pump repair requires pulling from well.	Repair to pump or motor requires pulling from well.
Pump capacity depends on the size of the cylinder (displacement) and the number of strokes per minute. Pressures are limited by the strength of the pumping equipment and the motor horsepower.		Operates usually at either 1,760 rpm or 3,500 rpm, depending on kind of power used. Usually used for pumping large quantities of water from deep wells. Pump capacity depends on the design, diameter and speed of the impellers. The pressure depends on the diameter, speed and number of impellers.	Pump capacity depends upon the design of the rotors. Can be used in 4" or larger wells.
Can be offset from the water source.	Double acting pumping barrels are available that pump 65% more water using 15% more horsepower.		
			

Table 441-7. Well descriptions.

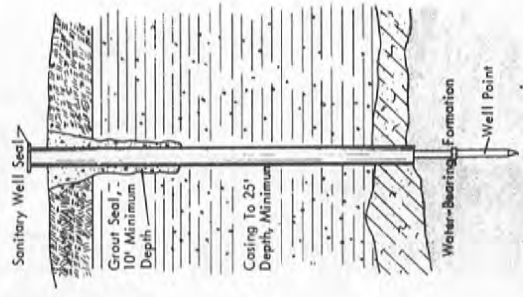
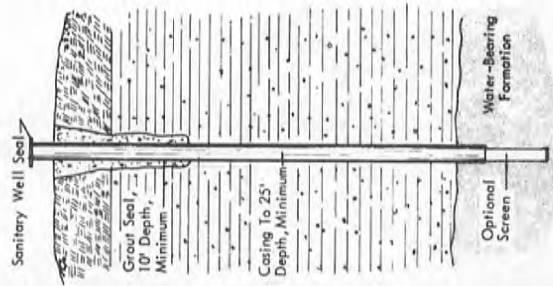
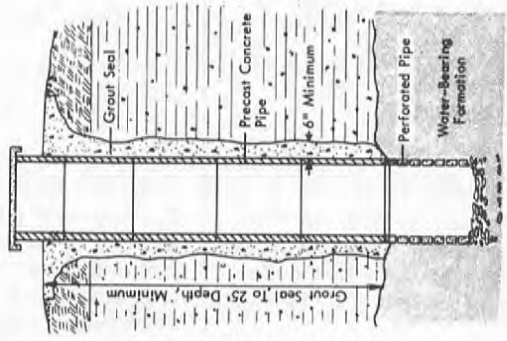
	Drilled percussion method	Drilled rotary hydraulic method	Jetted	Driven	Bored	Dug
Depth	0 to 1,000 feet	0 to 1,000 feet	0 to 100 feet	0 to 50 feet	0 to 100 feet	0 to 50 feet
Diameter	4 to 18 inches	4 to 24 inches	4 to 12 inches	1 1/4 to 2 inches	2 to 30 inches	3 to 20 feet
Construction Method	A heavy drill bit and stem is raised and dropped within a casing that is installed during the drilling. The bit dislodges material, and the material is mixed with water and brought up with a bailer. Sometimes the casing is not installed through solid rock.	A rotating bit breaks up material, and the material is mixed with drilling fluid (called mud) which carries the material out of the hole. After the hole is complete, a metal casing is inserted.	Water under pressure is forced down a riser pipe and loosens the material around the washing point. The loosened material is drawn up, as the pipe and washing point are lowered into the ground.	A specially-constructed point attached to a series of pipe sections is driven into the ground with a maul, drive shoe, or pile driver. The metal pipe sections are fitted together during driving. A pilot hole is desirable to protect the screen of the final well.	A power or hand auger removes the earth. The casing is usually tile or pipe of concrete, steel, or clay capable of withstanding the side loads.	Dug with pick and shovel, or power equipment if diameter is over 4 feet. The walls are commonly of brick, stone, concrete, or precast concrete pipe.
Precautions	Little trouble with surface contamination. At least upper 10' of completed well must be sealed with grout.		A protective casing should be installed to a depth of at least 25 feet to protect against surface water contamination.	Care of the driving point when the final well screen is contained within it.	Needs care to assure sealing. Will not work well in soils that will cave easily.	Well lining must be sealed tightly to prevent contamination. Some means of shoring the walls is needed during construction. Needs careful backfilling. Ventilate deep holes while hand digging.
Limitations	Can be used in all types of formations.	Sometimes difficult to recognize water-bearing formations because of the "mud" used to remove the drillings. Sometimes difficult to drill in boulders.	Can be jetted in only fine porous materials.	Yields will be small to moderate because of smallness of pipe. Cannot be driven into coarse or cemented gravel, boulders, sandstone, limestone, and dense rock.	Somewhat easily contaminated. Can be bored only a few feet below the water table. Difficult boring in boulders and dense rock. Cannot bore into cemented sandstone or limestone.	Many fail in periods of drought. Easily contaminated. Can be dug only a few feet below the water table. Cannot be in dense rock.
	 Sanitary Well Seal Grout Seal, 10' Minimum Depth Casing To 25' Depth, Minimum Water-Bearing Formation Well Point JETTED OR DRIVEN WELL with driven well point	 Sanitary Well Seal Grout Seal, 10' Depth, Minimum Casing To 25' Depth, Minimum Optional Screen Water-Bearing Formation DRILLED WELL	 Sanitary Well Seal Grout Seal, To 25' Depth, Minimum Precast Concrete Pipe 6" Minimum Perforated Pipe Water-Bearing Formation BORED or DUG WELL			

Table 441-8. Characteristics of piping.

	Plastic Pipe	Copper	Galvanized Steel
Corrosive Soils	Generally unaffected by any type of soil	Affected by some soils.	Deteriorates rapidly in acid soils
Pipe Corrosion	Very resistant to inside pipe corrosion	Will be affected by water containing free carbon dioxide.	Will corrode if water is acidic, alkaline, or hard
Water Pressure	Recommended water pressures depend on type of plastic. Use pipe with pressure rating at least 80.	Will withstand high water pressures	Will withstand high water pressures
Ease of Installation	The easiest to install. Joints are easy to make.	Rigid tubing requires sweated joints which are easier than threaded. Flexible tubing requires flaring and fitting.	Requires the most time and effort. Joints must be fitted and threaded.
Cost	Usually the least expensive in materials and labor	Usually the most expensive in materials, but has moderate labor cost	Moderate material cost, but usually requires high labor cost
Codes	Codes vary from one area to another. Some codes may limit the use of, or make it mandatory to use, one kind of pipe. Be sure to check local codes before starting construction.		
Limitations	Can be damaged by sharp objects. Will flatten under excessive external pressures; most kinds cannot be used for hot-water pipes. Will absorb gas and oil which cause taste in the water. May be damaged by rodents.	Some soils may cause deterioration	Should not be used for underground piping as soils often cause deterioration. Cannot be used for all kinds of water.

Water Treatment

All water from natural sources contains impurities. Some of these impurities adversely affect the usefulness and suitability of water, while others may improve its palatability.

Pure water is tasteless, colorless, and odorless, and is one of the best solvents available. Because pure water is such a good solvent, it picks up impurities easily. Most impurities are picked up naturally, but some are added, either accidentally or intentionally, by man.

Needed quality

Acceptable quality depends on the ultimate use of the water. For example, drinking water must be of high quality—safe and palatable.

Potable = safe to drink.

Palatable = nice to drink; acceptable flavor and, usually, appearance and odor.

Table 441-9. Chemical concentrations that cause odor and/or taste.*

Chemical	Concentration in mg/l	Chemical	Concentration in mg/l
Chlorides	100-250	Copper	1
Total dissolved solids	500-1000	Hydrogen Sulfide	0.1-0.2
		Iron	1.0-2.0
		Zinc	5

*Many individuals will accept greater concentrations.

Table 441-10. Maximum allowable chemical concentrations in drinking water.

Chemical	Maximum Concentration in mg/l	Chemical	Maximum Concentration in mg/l
Arsenic	0.05	Lead	0.05
Barium	1.00	Nitrate ²	45.0
Cadmium	0.01	Selenium	0.01
Chromium	0.05	Silver ³	0.05
Cyanide	0.20	Sulfate ³	250.0
Fluoride ¹	1.4 to 2.4		

¹Consult local health authority for optimum and maximum amounts for your area.

²Applies only to bottle-fed infants not receiving solid food.

³Less sensitive individuals can adjust to amounts of 1,000 mg/l or more without laxative effects.

Source: US PHS Drinking Water Standards.

Table 441-11. Recommended water qualities for various uses.

Use	Quality			
	Safe	Palatable	Soft	Non-Staining
Drinking	X	X		
Food preparation	X	X	X	X
Personal hygiene	X	X	X	X
Dish and dairy utensil washing	X		X	X
Clothes washing	X		X	X
Toilet flushing				X

Table 441-12. Water quality problems and typical solutions.

Problem	Possible Cause	Test for	Typical Corrective Procedures (one or several procedures may be needed)
Diseases such as typhoid fever, dysentery, diarrhea, hepatitis, and others	Disease-producing bacteria, virus, protozoa, etc.	Coliform bacteria	Repair or reconstruct the complete water system to keep out pollutants; then disinfect, retest, and if the test results are satisfactory from 3 or more samples taken 2 weeks apart, use the water. If the results are unsatisfactory, either • Develop a new water source; disinfect; test, and if satisfactory, use; or • Install and properly operate continuous disinfection equipment.
Rust or black colored water. Stained clothes and fixtures. Reduced water flow. Discolored, unpalatable food and beverages.	Iron or Manganese	Iron and Manganese	• Aerate the water in a storage tank (pressurized or non-pressurized) and then run water through a sediment filter. • Continuously chlorinate the water and run it through a sediment filter or carbon filter. • Install a sediment filter and a softener • Install a softener, but only if the water is clear. • Install a potassium permanganate regenerated oxidizing filter and a softener. If water pH is less than 7.0, the acid must be neutralized ahead of the filter.
Rust colored slime in toilet tank and pipes. Fuzzy particles in water. Staining. Reduced water flow.	Iron bacteria	Iron bacteria	• Shock chlorinate the well and system, blow out all pipes, and shock chlorinate again. Do this when needed. • Install a continuous chlorination system and carbon filter.
Clothes becoming gray even with good washing. Scum on wash and bath water after using soap. Water heater takes long to heat water. Reduced water flow.	Hard water (dissolved minerals)	Calcium and Magnesium	• Correctly size, install, and operate a water softener. • Use small amount of packaged water softener in baths, washer, etc. • Clogged pipes, water heaters, and other equipment must be cleaned or replaced.
Smelly water -- rotten egg odor. Rapid tarnishing of silverware. Staining, black color	Hydrogen sulfide	Hydrogen sulfide	• Install a continuous chlorination system and carbon filter. • Aerate the water. Install a sediment and/or carbon filter if needed. • Install a potassium permanganate regenerated oxidizing filter. • Clogged and corroded pipes and equipment must be cleaned or replaced.
Corroded metal parts of pump and water system. Staining, green color	Low pH (Acid water)	pH	• Install a continuous soda ash solution feeder. • Install a neutralizer tank containing limestone chips
Cloudy water	Particles of suspended or colored matter	Turbidity and color	• Install a sediment filter, and possibly a coagulant feeder ahead of the filter.
Gassy well and water	Decay of organic matter	Methane	• Install gas release valve on pressure tank and vent to outdoors. • Aerate water in a non-pressurized storage tank.

CONVERSIONS			ABBREVIATIONS	
To Convert From	To	Multiply By		
Acre feet	Gallons	325851	in -- inches	
Head (feet of water)	Pressure	0.434	ft -- feet	
Gallons per minute	Gallons per hour	60	gal -- gallons	
Milligrams per liter	Parts per million	1	gpm -- gallons per minute	
Pressure (pounds per square inch)	Head (feet of water)	2.31	gpd -- gallons per day	
			gph -- gallons per hour	
			gpg -- grains per gallon	
			mg/l -- milligrams per liter	
			ppm -- parts per million	
			psi -- pound per square inch	

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CHAPTER 511 BEAM FORMULAS

Introduction

Equivalent Tabular Loads

Tabular loads are those listed in tables for specific materials and spans, and are usually expressed in total uniform load or in uniform load per unit length of beam. Tabular Loads are calculated from the bending moment in a beam resulting from a uniform load, the size of a specified beam, and the allowable stresses in the specified material.

Allowable load tables can be used for load patterns other than uniform load by converting the moment from the actual load pattern to its Equivalent Tabular Load, which is the uniform load that would result in the same maximum moment.

Equivalent Tabular Load (ETL).

1. Find the maximum bending moment resulting from the actual load pattern.
2. Convert units to those used in the load tables, usually feet and pounds.
3. If table lists total uniform load:

$$ETL = \frac{8 \times \text{maximum moment}}{\text{beam length}}$$

If table lists load per unit length:

$$ETL = \frac{8 \times \text{maximum moment}}{(\text{beam length})^2}$$

4. Select a beam that will support the ETL.
5. Check the selected beam for shear and deflection using equations for the actual load pattern.

Example: Simple beam with one concentrated load, P , at midspan. Maximum moment (Eq 511-8) = $PL/4$.

If load table lists total uniform load:

$$ETL = \frac{8 \times PL/4}{L} = 2P$$

If load table lists load per unit length:

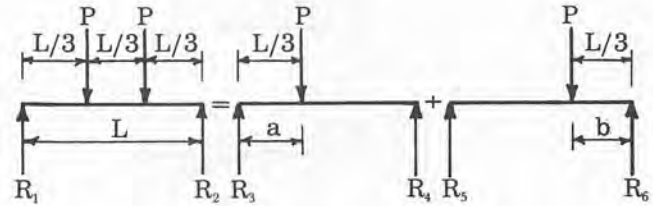
$$ETL = \frac{8 \times PL/4}{L^2} = 2P/L$$

Select a beam to support $2P$ or $2P/L$.

Superposition of Loads

Given a beam with more than one load on it, the net effect of the loads at one point in the beam is equal to the sum of the effects of each load individually at that point. This is true for bending moments, shears, deflections, etc.

Example:



The net effect of both loads is found using the equations for a single concentrated load at any point:

Moment at midspan:

Load left of center = $Pa/2 = PL/6$ @ $a = L/3$

Load right of center = $Pb/2 = PL/6$ @ $b = L/3$

Total Moment at midspan = $PL/3$

Check: see Fig 511-10; moment @ midspan from 2 equal loads placed symmetrically @ $L/3$ from each end = $PL/3$, which agrees with the calculation by superposition.

Similarly for end reactions:

$$R_1 = R_3 + R_5$$

$$R_2 = R_4 + R_6$$

And for deflection @ midspan:

$$\text{Load left of center} = \frac{Pa(L-x)(-a^2 - x^2 + 2xL)}{6EI}$$

$$= \frac{23PL^3}{(36)^2EI}$$

@ $a = L/3$ and $x = L/2$

Similarly for right load, and substituting b for a in the above equations,

$$\text{deflection at midspan} = \frac{23PL^3}{(36)^2EI}$$

$$\text{Total deflection} = \frac{46 PL^3}{(36)^2EI} = \frac{23PL^3}{648EI}$$

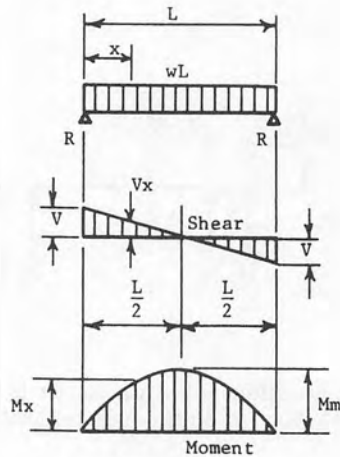
Check: see Fig 511-10; deflection at midspan = $\frac{Pa}{24EI}(3L^2 - 4a^2)$ where $a = L/3$

$$= \frac{23PL^3}{648EI} \text{ which agrees with the computation above.}$$

Symbol Units

For moments in ft-lb add lengths (L, a, b, c, x , etc) should be in ft and all distributed loads (w) should be in lb/ft. Use lengths and distributed loads in inches and lb/in. respectively for moments in in.-lb. To obtain deflections in inches the length and load units should be inches and lb/in. Any compatible length and load units (in. and lb/in. or ft and lb/ft) will yield correct shear and reaction values.

Simple Beams



Eq 511-1

$$R = V \dots \dots \dots = \frac{wL}{2}$$

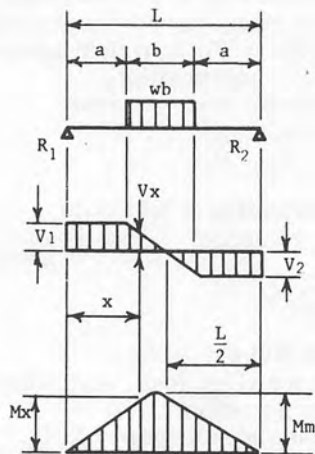
$$V_x \dots \dots \dots = w\left(\frac{L}{2} - x\right)$$

$$M_m \text{ [at } L/2] \dots \dots \dots = \frac{wL^2}{8}$$

$$M_x \dots \dots \dots = \frac{wx}{2}(L - x)$$

$$D_m \text{ [at } L/2] \dots \dots \dots = \frac{5wL^4}{384EI}$$

$$D_x \dots \dots \dots = \frac{wx}{24EI}(L^3 - 2Lx^2 + x^3)$$



Eq 511-2

$$R_1 = R_2 = V_1 = V_2 \dots \dots \dots = \frac{wb}{2}$$

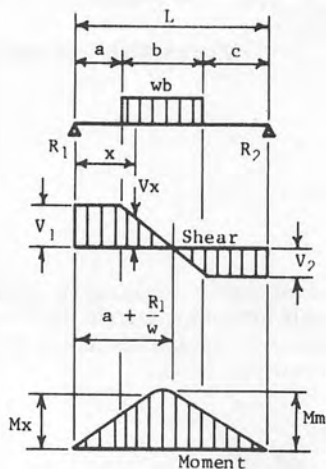
$$V_x \text{ [at } a < x < (a + b)] \dots \dots \dots = \frac{wb}{2} - w(x - a)$$

$$M_m \text{ [at } L/2] \dots \dots \dots = \frac{wb}{8}(2L - b)$$

$$M_x \text{ [at } x < a] \dots \dots \dots = \frac{wbx}{2}$$

$$M_x \text{ [at } a < x < (a + b)] \dots \dots \dots = \frac{wbx}{2} - \frac{w(x - a)^2}{2}$$

$$D_m \text{ [at } x = L/2] \dots \dots \dots = \frac{5wL^4}{384EI} - \frac{wa^2}{48EI}(3L^2 - 2a^2)$$



Eq 511-3

$$R_1 = V_1 \text{ [max. at } a < c] \dots \dots \dots = \frac{wb}{2L}(2c + b)$$

$$R_2 = V_2 \text{ [max. at } a > c] \dots \dots \dots = \frac{wb}{2L}(2a + b)$$

$$V_x \text{ [at } a < x < (a + b)] \dots \dots \dots = R_1 - w(x - a)$$

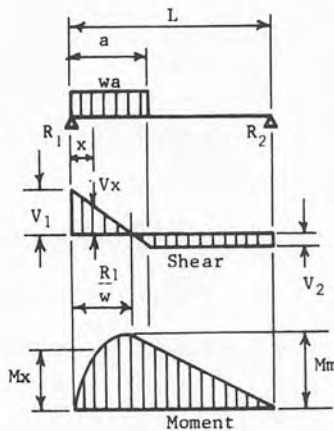
$$M_m \text{ [at } x = a + \frac{R_1}{w}] \dots \dots \dots = R_1(a + \frac{R_1}{2w})$$

$$M_x \text{ [at } x < a] \dots \dots \dots = R_1x$$

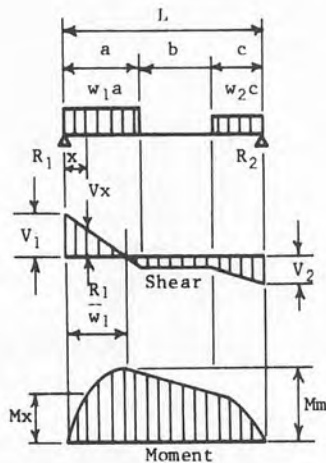
$$M_x \text{ [at } a < x < (a + b)] \dots \dots \dots = R_1x - \frac{w}{2}(x - a)^2$$

$$M_x \text{ [at } (a + b) < x < L] \dots \dots \dots = R_2(L - x)$$

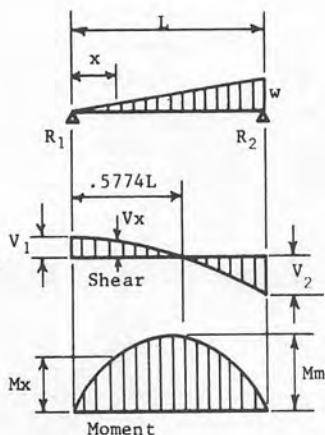
$$D_m \text{ [when } a \text{ and } c < L/2] \dots \dots \dots = \frac{5wL^4}{384EI} - \frac{w}{96EI}(3L^2a^2 - 2a^4 + 3L^2c^2 - 2c^4)$$


Eq 511-4

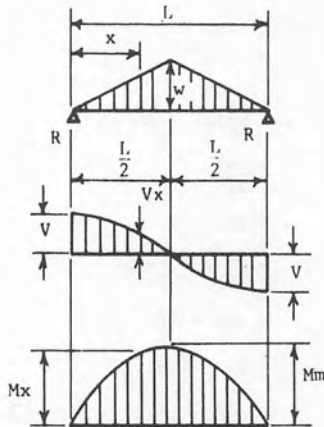
$$\begin{aligned}
 R_1 = V_1 \text{ max.} & \dots \dots \dots = \frac{wa}{2L}(2L - a) \\
 R_2 = V_2 & \dots \dots \dots = \frac{wa^2}{2L} \\
 V_x \text{ [} @ x < a \text{]} & \dots \dots \dots = R_1 - wx \\
 M_m \text{ [} @ x = \frac{R_1}{w} \text{]} & \dots \dots \dots = \frac{R_1^2}{2w} \\
 M_x \text{ [} @ x < a \text{]} & \dots \dots \dots = R_1x - \frac{wx^2}{2} \\
 M_x \text{ [} @ a < x < L \text{]} & \dots \dots \dots = R_2(L - x) \\
 D_x \text{ [} @ x < a \text{]} & \dots \dots \dots = \frac{wx}{24EIL}(a^2(2L - a)^2 - 2ax^2(2L - a) + Lx^3) \\
 D_x \text{ [} @ x > a \text{]} & \dots \dots \dots = \frac{wa^2(L - x)}{24EIL}(4xL - 2x^2 - a^2)
 \end{aligned}$$

Eq 511-5


$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{w_1a(2L - a) + w_2c^2}{2L} \\
 R_2 = V_2 & \dots \dots \dots = \frac{w_2c(2L - c) + w_1a^2}{2L} \\
 V_m \text{ [} @ w_1a > w_2c \text{]} & \dots \dots \dots = R_1 \\
 V_m \text{ [} @ w_1a < w_2c \text{]} & \dots \dots \dots = R_2 \\
 V_x \text{ [} @ x < a \text{]} & \dots \dots \dots = R_1 - w_1x \\
 M_m \text{ [} @ x = \frac{R_1}{w_1} \text{ @ } R_1 < w_1a \text{]} & \dots \dots \dots = \frac{R_1^2}{2w_1} \\
 M_m \text{ [} @ x = L - \frac{R_2}{w_2} \text{ @ } R_2 < w_2c \text{]} & \dots \dots \dots = \frac{R_2^2}{2w_2} \\
 M_x \text{ [} @ x < a \text{]} & \dots \dots \dots = R_1x - \frac{w_1x^2}{2} \\
 M_x \text{ [} @ a < x < (a + b) \text{]} & \dots \dots \dots = R_1x - \frac{w_1a}{2}(2x - a) \\
 M_x \text{ [} @ x > (a + b) \text{]} & \dots \dots \dots = R_2(L - x) - \frac{w_2(L - x)^2}{2} \\
 D_t \text{ [when } a \text{ and } c < L/2 \text{]} & \dots \dots \dots = \frac{w_1a^2}{96EI}(3L^2 - 2a^2) \\
 & \dots \dots \dots + \frac{w_2c^2}{96EI}(3L^2 - 2c^2)
 \end{aligned}$$


Eq 511-6

$$\begin{aligned}
 W & \dots \dots \dots = wL/2 \\
 R_1 = V_1 & \dots \dots \dots = wL/6 \\
 R_2 = V_2 \text{ max.} & \dots \dots \dots = wL/3 \\
 V_x & \dots \dots \dots = \frac{wL}{6} - \frac{wx^2}{2L} \\
 M_m \text{ [} @ x = .5774L \text{]} & \dots \dots \dots = \frac{wL^2}{9\sqrt{3}} = 0.0642wL^2 \\
 M_x & \dots \dots \dots = \frac{wx}{6L}(L^2 - x^2) \\
 D_m \text{ [} @ x = .5193L \text{]} & \dots \dots \dots = 0.00652 \frac{wL^4}{EI} \\
 D_x & \dots \dots \dots = \frac{wx}{360EIL}(3x^4 - 10L^2x^2 + 7L^4)
 \end{aligned}$$



Eq 511-7

$$W \dots \dots \dots = wL/2$$

$$R = V \dots \dots \dots = wL/4$$

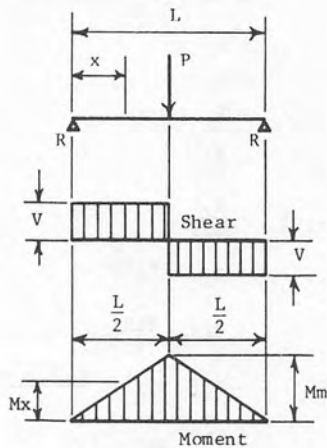
$$V_x \text{ [} @ x < \frac{L}{2} \text{]} \dots \dots \dots = \frac{w}{4L}(L^2 - 4x^2)$$

$$M_m \text{ [} @ \text{ center]} \dots \dots \dots = wL^2/12$$

$$M_x \text{ [} @ x < \frac{L}{2} \text{]} \dots \dots \dots = \frac{wx}{2}(\frac{L}{2} - \frac{2x^2}{3L})$$

$$D_m \text{ [} @ \text{ center]} \dots \dots \dots = \frac{wL^4}{120EI}$$

$$D_x \dots \dots \dots = \frac{wx}{960EIL}(5L^2 - 4x^2)^2$$



Eq 511-8

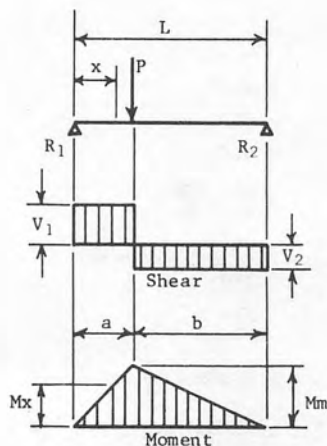
$$R = V \dots \dots \dots = P/2$$

$$M_m \text{ [} @ \text{ load]} \dots \dots \dots = PL/4$$

$$M_x \text{ [} @ x < L/2 \text{]} \dots \dots \dots = Px/2$$

$$D_m \text{ [} @ \text{ load]} \dots \dots \dots = \frac{PL^3}{48EI}$$

$$D_x \text{ [} @ x < L/2 \text{]} \dots \dots \dots = \frac{Px}{48EI}(3L^2 - 4x^2)$$



Eq 511-9

$$R_1 = V_1 \text{ [max. } @ a < b \text{]} \dots \dots \dots = Pb/L$$

$$R_2 = V_2 \text{ [max. } @ a > b \text{]} \dots \dots \dots = Pa/L$$

$$M_m \text{ [} @ \text{ load]} \dots \dots \dots = Pab/L$$

$$M_x \text{ [} @ x < a \text{]} \dots \dots \dots = Pbx/L$$

$$M_x \text{ [} @ a < x < L \text{]} \dots \dots \dots = \frac{Pa}{L}(L - x)$$

$$D_m \text{ [} @ x = \sqrt{\frac{a(a+2b)}{3}} \text{ } @ a > b \text{]} \dots \dots \dots = \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27 EIL}$$

$$D_a \text{ [} @ \text{ load]} \dots \dots \dots = \frac{Pa^2b^2}{3EIL}$$

$$D_x \text{ [} @ x < a \text{]} \dots \dots \dots = \frac{Pbx}{6EIL}(L^2 - b^2 - x^2)$$

$$D_x \text{ [} @ a < x < L \text{]} \dots \dots \dots = \frac{Pa}{6EIL}(L - x)(-a^2 + 2xL - x^2)$$

2 Equal loads

Eq 511-10 $a = b = c = L/3$

$$R = V \dots \dots \dots = P$$

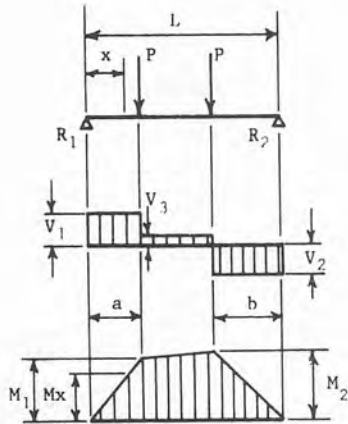
$$M_m \text{ [between loads]} \dots \dots \dots = PL/3$$

$$M_x \text{ [@ } x < L/3] \dots \dots \dots = Px$$

$$D_m \text{ [@ center]} \dots \dots \dots = \frac{23PL^3}{648EI}$$

$$D_x \text{ [@ } x < a] \dots \dots \dots = \frac{Px}{6EI} \left(\frac{2L^2}{3} - x^2 \right)$$

$$D_x \text{ [@ } a < x < (L - a)] \dots \dots \dots = \frac{PL}{18EI} (3Lx - 3x^2 - L^2/9)$$



Eq 511-11 $a = b \neq c$

$$R = V \dots \dots \dots = P$$

$$M_m \text{ [between loads]} \dots \dots \dots = Pa$$

$$M_x \text{ [@ } x < a] \dots \dots \dots = Px$$

$$D_m \text{ [@ center]} \dots \dots \dots = \frac{Pa}{24EI} (3L^2 - 4a^2)$$

$$D_x \text{ [@ } x < a] \dots \dots \dots = \frac{Px}{6EI} (3La - 3a^2 - x^2)$$

$$D_x \text{ [@ } a < x < (L - a)] \dots \dots \dots = \frac{Pa}{6EI} (3Lx - 3x^2 - a^2)$$

Eq 511-12 $a \neq b \neq c$

$$R_1 = V_1 \text{ [max. @ } a < b] \dots \dots \dots = \frac{P}{L} (L - a + b)$$

$$R_2 = V_2 \text{ [max. @ } a > b] \dots \dots \dots = \frac{P}{L} (L - b + a)$$

$$V_3 \dots \dots \dots = \frac{P}{L} (b - a)$$

$$M_1 \text{ [max. @ } a > b] \dots \dots \dots = R_1 a$$

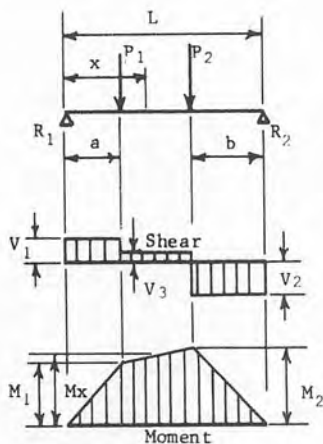
$$M_2 \text{ [max. @ } a < b] \dots \dots \dots = R_2 b$$

$$M_x \text{ [@ } x < a] \dots \dots \dots = R_1 x$$

$$M_x \text{ [@ } a < x < (L - b)] \dots \dots \dots = R_1 x - P(x - a)$$

$$M_x \text{ [@ } (L - b) < x < L] \dots \dots \dots = R_2 (L - x)$$

NOTE: For deflections use superposition of 2 single concentrated loads.



2 Unequal loads

Eq 511-13 $P_1 \neq P_2$

$$R_1 = V_1 \dots \dots \dots = \frac{P_1 (L - a) + P_2 b}{L}$$

$$R_2 = V_2 \dots \dots \dots = \frac{P_1 a + P_2 (L - b)}{L}$$

$$V_3 \dots \dots \dots = R_1 - P_1$$

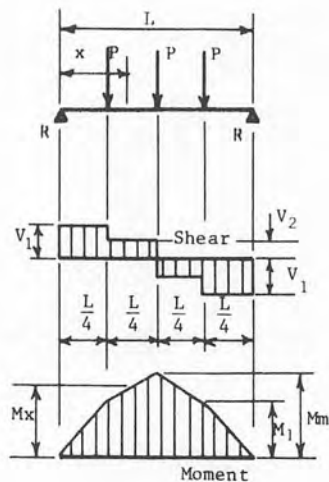
$$M_1 \text{ [max. @ } R_1 < P_1] \dots \dots \dots = R_1 a$$

$$M_2 \text{ [max. @ } R_2 < P_2] \dots \dots \dots = R_2 b$$

$$M_x \text{ [@ } x < a] \dots \dots \dots = R_1 x$$

$$M_x \text{ [@ } a < x < (L - b)] \dots \dots \dots = R_1 x - P_1 (x - a)$$

NOTE: For deflections use superposition of 2 single concentrated loads.



Eq 511-14

$$R = V_1 \dots\dots\dots = 3P/2$$

$$V_2 \dots\dots\dots = P/2$$

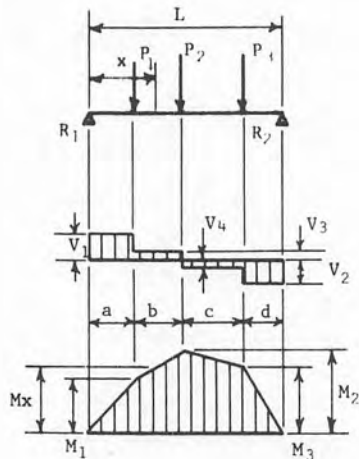
$$M_x \text{ [} @ x < L/4 \text{]} \dots\dots\dots = \frac{3Px}{2}$$

$$M_x \text{ [} @ L/4 < x < L/2 \text{]} \dots\dots\dots = \frac{Px}{2} + \frac{PL}{4}$$

$$M_1 \text{ [} @ x = L/4 \text{]} \dots\dots\dots = \frac{3PL}{8}$$

$$M_m \text{ [} @ x = L/2 \text{]} \dots\dots\dots = PL/2$$

$$D_m \text{ [} @ x = L/2 \text{]} \dots\dots\dots = \frac{19PL^3}{384 EI}$$



Eq 511-15

$$R_1 = V_1 \dots\dots\dots = \frac{P_1(L - a) + P_2(c + d) + P_3d}{L}$$

$$R_2 = V_2 \dots\dots\dots = \frac{P_1a + P_2(a + b) + P_3(L - d)}{L}$$

$$V_3 \dots\dots\dots = R_1 - P_1$$

$$V_4 \dots\dots\dots = R_1 - P_1 - P_2$$

$$M_1 \dots\dots\dots = R_1a$$

$$M_2 \dots\dots\dots = R_1(a + b) - P_1b$$

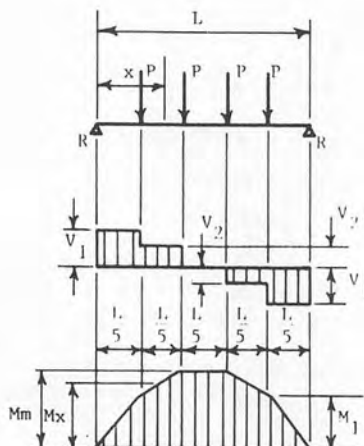
$$M_3 \dots\dots\dots = R_1(L - d) - P_1(b + c) - P_2c$$

$$M_m \text{ [when } P_1 \geq R_1 \text{]} \dots\dots\dots = M_1$$

$$M_m \text{ [when } P_1 + P_2 \geq R_1, P_2 + P_3 \geq R_2 \text{]} = M_2$$

$$M_m \text{ [when } P_3 \geq R_2 \text{]} \dots\dots\dots = M_3$$

NOTE: For deflections use superposition of 3 single concentrated loads.



Eq 511-16

$$R = V_1 \dots\dots\dots = 2P$$

$$V_2 \dots\dots\dots = P$$

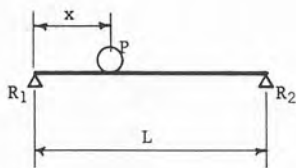
$$M_x \text{ [} @ x < L/5 \text{]} \dots\dots\dots = 2Px$$

$$M_x \text{ [} @ L/5 < x < 2L/5 \text{]} \dots\dots\dots = Px + PL/5$$

$$M_1 \dots\dots\dots = \frac{2PL}{5}$$

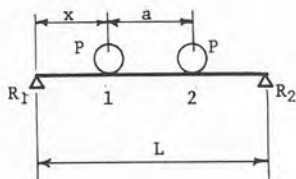
$$M_m \text{ [} @ x = L/2 \text{]} \dots\dots\dots = \frac{3PL}{5}$$

$$D_x \text{ [} @ x = L/2 \text{]} \dots\dots\dots = \frac{3.78 PL^3}{60EI}$$


Eq 511-17

$$R_1m = V_1m \quad [@ \ x = 0] \quad . . . = P$$

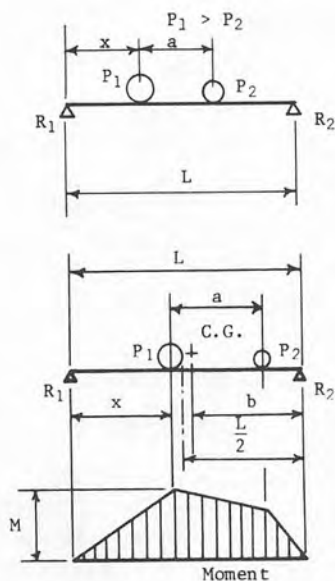
$$Mm \quad [@ \ \text{load, } @ \ x = \frac{L}{2}] \quad . . . = \frac{PL}{4}$$


Eq 511-18

$$R_1m = V_1m \quad [@ \ x = 0] \quad . . . = P(2 - \frac{a}{L})$$

$$Mm \quad \left\{ \begin{array}{l} [@ \ a < .586L \\ [@ \ \text{load 1 } @ \ x = \frac{1}{2}(L - \frac{a}{2}) \end{array} \right] . . = \frac{P}{2L}(L - \frac{a}{2})^2$$

$$\left\{ \begin{array}{l} [@ \ a > .586L \text{ with one load at} \\ [\text{center of span} \end{array} \right] . . = \frac{PL}{4}$$


Eq 511-19

$$R_1m = V_1m \quad [@ \ x = 0] \quad . . . = P_1 + P_2 \frac{L - a}{L}$$

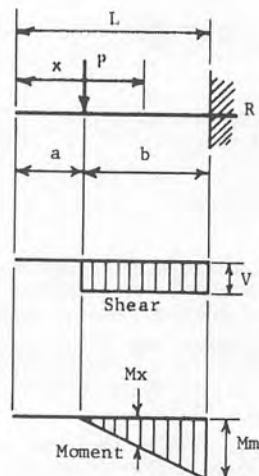
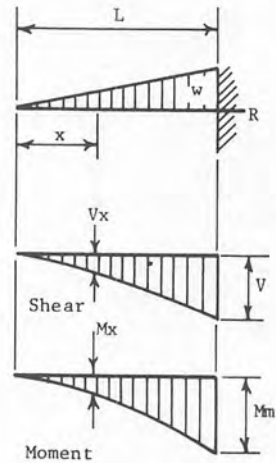
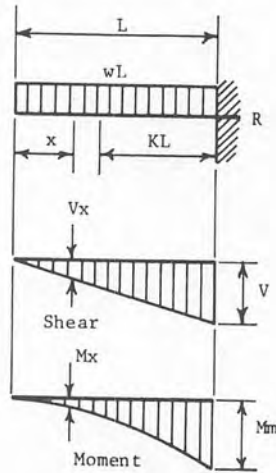
$$Mm \quad \left\{ \begin{array}{l} [\text{under } P_1, @ \ x = \frac{1}{2}(L - \frac{P_2 a}{P_1 + P_2})] . . = (P_1 + P_2) \frac{x^2}{L} \\ [Mm \text{ may be with } P_1 \text{ at center of} \\ [\text{span and } P_2 \text{ off span} \end{array} \right] . . = \frac{P_1 L}{4}$$

Maximum shear is at one support when one of the loads is at that support. With several moving loads, locate them for maximum shear by trial.

Maximum moment is under one of the loads when that load is as far from one support as the center of gravity of all the moving loads on the beam is from the other support.

\$Mm\$ is at \$P_1\$ when \$x = b\$, and when the span center line is midway between the center of gravity of loads and the nearest concentrated load.

Cantilever Beams



Eq 511-20

$$\begin{aligned}
 R = V & \dots \dots \dots = wL \\
 Vx & \dots \dots \dots = wx \\
 Mm \text{ [@ fixed end] } & \dots \dots \dots = \frac{-wL^2}{2} \\
 Mx & \dots \dots \dots = \frac{-wx^2}{2} \\
 Dm \text{ [@ free end] } & \dots \dots \dots = \frac{wL^4}{8EI} \\
 Dx & \dots \dots \dots = \frac{w}{24EI}(x^4 - 4L^3x + 3L^4)
 \end{aligned}$$

For partial load from support to distance KL , substitute KL for L . Measure x from left end of KL . Dm then becomes D_{KL} .

Eq 511-21

$$\begin{aligned}
 W & \dots \dots \dots = wL/2 \\
 R = V & \dots \dots \dots = wL/2 \\
 Vx & \dots \dots \dots = wx^2/2L \\
 Mm \text{ [@ fixed end] } & \dots \dots \dots = -wL^2/6 \\
 Mx & \dots \dots \dots = -wx^3/6L \\
 Dm \text{ [@ free end] } & \dots \dots \dots = \frac{wL^4}{30EI} \\
 Dx & \dots \dots \dots = \frac{w}{120EIL}(x^5 - 5L^4x + 4L^5)
 \end{aligned}$$

Eq 511-22 $a = 0$ (load at free end)

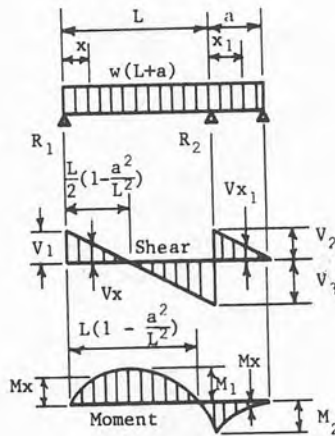
$$\begin{aligned}
 R = V & \dots \dots \dots = P \\
 Mm \text{ [@ fixed end] } & \dots \dots \dots = -PL \\
 Mx & \dots \dots \dots = -Px \\
 Dm \text{ [@ free end] } & \dots \dots \dots = \frac{PL^3}{3EI} \\
 Dx & \dots \dots \dots = \frac{P}{6EI}(2L^3 - 3L^2x + x^3)
 \end{aligned}$$

Eq 511-23 $a \neq 0$

$$\begin{aligned}
 R = V \text{ [@ } a < x < L \text{] } & \dots \dots \dots = P \\
 Mm \text{ [@ fixed end] } & \dots \dots \dots = -Pb \\
 Mx \text{ [@ } x > a \text{] } & \dots \dots \dots = -P(x - a) \\
 Dm \text{ [@ free end] } & \dots \dots \dots = \frac{Pb^2}{6EI}(3L - b) \\
 Da \text{ [@ load] } & \dots \dots \dots = \frac{Pb^3}{3EI} \\
 Dx \text{ [@ } x < a \text{] } & \dots \dots \dots = \frac{Pb^2}{6EI}(3L - 3x - b) \\
 Dx \text{ [@ } x > a \text{] } & \dots \dots \dots = \frac{P(L - x)^2}{6EI}(3b - L + x)
 \end{aligned}$$

Overhang Beams

Eq 511-24



$$R_1 = V_1 \dots \dots \dots = \frac{w}{2L}(L^2 - a^2)$$

$$R_2 = V_2 + V_3 \dots \dots \dots = \frac{w}{2L}(L + a)^2$$

$$V_2 \dots \dots \dots = wa$$

$$V_3 \dots \dots \dots = \frac{w}{2L}(L^2 + a^2)$$

$$V_x \dots \dots \dots = R_1 - wx$$

$$V_{x_1} \dots \dots \dots = w(a - x_1)$$

$$M_1 \text{ [} @ x = \frac{L}{2}(1 - \frac{a^2}{L^2}) \text{]} \dots \dots \dots = \frac{w}{8L^2}(L + a)^2(L - a)^2$$

$$M_2 \text{ [} @ R_2 \text{]} \dots \dots \dots = -\frac{wa^2}{2}$$

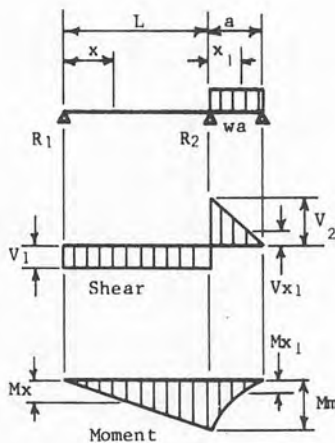
$$M_x \dots \dots \dots = \frac{wx}{2L}(L^2 - a^2 - xL)$$

$$M_{x_1} \dots \dots \dots = -\frac{w}{2}(a - x_1)^2$$

$$Dx \dots \dots \dots = \frac{wx}{24EI}(L^4 - 2L^2x^2 + Lx^3 - 2a^2L^2 + 2a^2x^2)$$

$$Dx_1 \dots \dots \dots = \frac{wx_1}{24EI}(4a^2L - L^3 + 6a^2x_1 - 4ax_1^2 + x_1^3)$$

Eq 511-25



$$R_1 = V_1 \dots \dots \dots = -\frac{wa^2}{2L}$$

$$R_2 = V_1 + V_2 \dots \dots \dots = \frac{wa}{2L}(2L + a)$$

$$V_2 \dots \dots \dots = wa$$

$$V_{x_1} \dots \dots \dots = w(a - x_1)$$

$$M_m \text{ [} @ R_2 \text{]} \dots \dots \dots = -\frac{wa^2}{2}$$

$$M_x \dots \dots \dots = -\frac{wa^2x}{2L}$$

$$M_{x_1} \dots \dots \dots = -\frac{w}{2}(a - x_1)^2$$

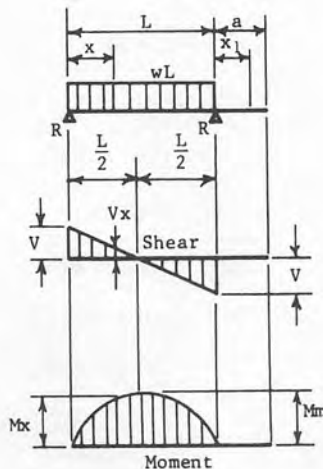
$$Dmx \text{ [} @ x = \frac{L}{3} \text{]} \dots \dots \dots = -\frac{wa^2L^2}{18\sqrt{3}EI} = -.03208\frac{wa^2L^2}{EI}$$

$$Dmx_1 \text{ [} @ x_1 = a \text{]} \dots \dots \dots = \frac{wa^3}{24EI}(4L + 3a)$$

$$Dx \dots \dots \dots = -\frac{wa^2x}{12EI}(L^2 - x^2)$$

$$Dx_1 \dots \dots \dots = \frac{wx_1}{24EI}(4a^2L + 6a^2x_1 - 4ax_1^2 + x_1^3)$$

Eq 511-26



$$R = V \dots \dots \dots = \frac{wL}{2}$$

$$V_x \dots \dots \dots = w(\frac{L}{2} - x)$$

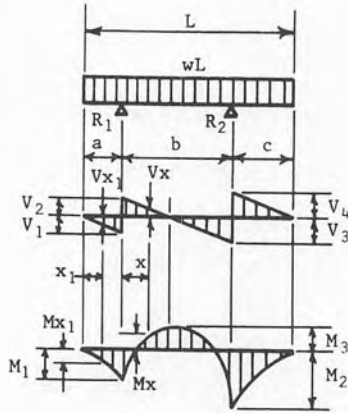
$$M_m \text{ [} @ \text{ center} \text{]} \dots \dots \dots = \frac{wL^2}{8}$$

$$M_x \dots \dots \dots = \frac{wx}{2}(L - x)$$

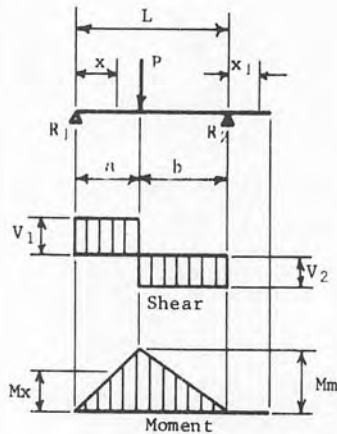
$$Dm \text{ [} @ \text{ center} \text{]} \dots \dots \dots = \frac{5wL^4}{384EI}$$

$$Dx \dots \dots \dots = \frac{wx}{24EI}(L^3 - 2Lx^2 + x^3)$$

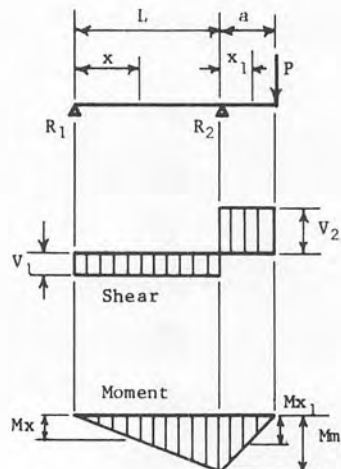
$$Dx_1 \dots \dots \dots = -\frac{wL^3x_1}{24EI}$$

**Eq 511-27**

$$\begin{aligned}
 R_1 & \dots \dots \dots = \frac{wL(L-2c)}{2b} \\
 R_2 & \dots \dots \dots = \frac{wL(L-2a)}{2b} \\
 V_1 & \dots \dots \dots = wa \\
 V_2 & \dots \dots \dots = R_1 - V_1 \\
 V_3 & \dots \dots \dots = R_2 - V_4 \\
 V_4 & \dots \dots \dots = wc \\
 Vx_1 & \dots \dots \dots = V_1 - wx_1 \\
 Vx \text{ [} @ x < L \text{]} & \dots \dots \dots = R_1 - w(a+x_1) \\
 Vm \text{ [} @ a < c \text{]} & \dots \dots \dots = R_2 - wc \\
 M_1 & \dots \dots \dots = -\frac{wa^2}{2} \\
 M_2 & \dots \dots \dots = -\frac{wc^2}{2} \\
 M_3 & \dots \dots \dots = R_1\left(\frac{R_1}{2w} - a\right) \\
 Mx \text{ [max. @ } x = \frac{R_1}{w} - a \text{]} & \dots \dots \dots = R_1x - \frac{w(a+x)^2}{2} \\
 Mx_1 & \dots \dots \dots = -\frac{wx_1^2}{2}
 \end{aligned}$$

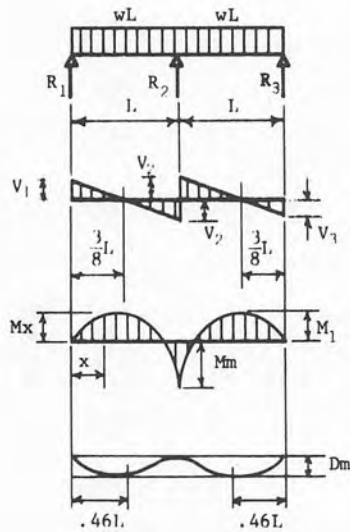
**Eq 511-28**

$$\begin{aligned}
 R_1 = V_1 \text{ [max. @ } a < b \text{]} & \dots \dots \dots = \frac{Pb}{L} \\
 R_2 = V_2 \text{ [max. @ } a > b \text{]} & \dots \dots \dots = \frac{Pa}{L} \\
 Mm \text{ [} @ \text{ load]} & \dots \dots \dots = \frac{Pab}{L} \\
 Mx \text{ [} @ x < a \text{]} & \dots \dots \dots = \frac{Pbx}{L} \\
 Dm \text{ [} @ x = \sqrt{\frac{a(a+2b)}{3}} \text{ @ } a > b \text{]} & \dots \dots \dots = \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EIL} \\
 Da \text{ [} @ \text{ load]} & \dots \dots \dots = \frac{Pa^2b^2}{3EIL} \\
 Dx \text{ [} @ x < a \text{]} & \dots \dots \dots = \frac{Pbx}{6EIL}(L^2 - b^2 - x^2) \\
 Dx \text{ [} @ x > a \text{]} & \dots \dots \dots = \frac{Pa(L-x)}{6EIL}(2Lx - x^2 - a^2) \\
 Dx_1 & \dots \dots \dots = \frac{Pabx_1}{6EIL}(L+a)
 \end{aligned}$$

Eq 511-29

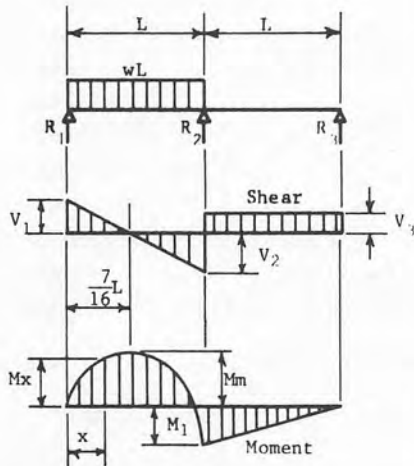
$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = -\frac{Pa}{L} \\
 R_2 = V_1 + V_2 & \dots \dots \dots = \frac{P}{L}(L+a) \\
 V_2 & \dots \dots \dots = P \\
 Mm \text{ [} @ R_2 \text{]} & \dots \dots \dots = -Pa \\
 Mx \text{ [between supports]} & \dots \dots \dots = -\frac{Pax}{L} \\
 Mx_1 \text{ [for overhang]} & \dots \dots \dots = -P(a-x_1) \\
 Dm \text{ [} @ x = \frac{L}{\sqrt{3}} \text{]} & \dots \dots \dots = -.06415 \frac{PaL^2}{EI} \\
 Dm \text{ [} @ x_1 = a \text{]} & \dots \dots \dots = \frac{Pa^2}{3EI}(L+a) \\
 Dx \text{ [between supports]} & \dots \dots \dots = -\frac{Pax}{6EIL}(L^2 - x^2) \\
 Dx_1 \text{ [for overhang]} & \dots \dots \dots = \frac{Px_1}{6EI}(2aL + 3ax_1 - x_1^2)
 \end{aligned}$$

Multi-Span Beams



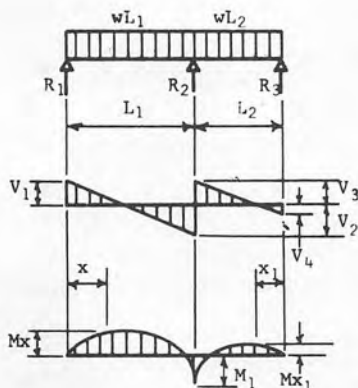
Eq 511-30

$$\begin{aligned}
 R_1 = V_1 = R_3 = V_3 & \dots \dots \dots = \frac{3wL}{8} \\
 R_2 & \dots \dots \dots = \frac{10wL}{8} \\
 V_2 = V_m & \dots \dots \dots = \frac{5wL}{8} \\
 M_m & \dots \dots \dots = -\frac{wL^2}{8} \\
 M_1 \text{ [} @ x = \frac{3L}{8} \text{]} & \dots \dots \dots = \frac{9wL^2}{128} \\
 Mx \text{ [} @ x < L \text{]} & \dots \dots \dots = \frac{3wLx}{8} - \frac{wx^2}{2} \\
 Dm \text{ [} @ x = \text{approx. } 0.461L \text{]} & \dots \dots \dots = \frac{wL^4}{185EI}
 \end{aligned}$$



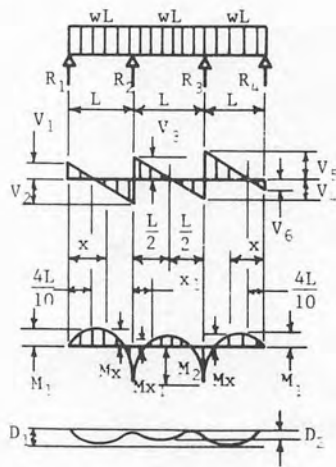
Eq 511-31

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{7}{16}wL \\
 R_2 = V_2 + V_3 & \dots \dots \dots = \frac{5}{8}wL \\
 R_3 = V_3 & \dots \dots \dots = -\frac{1}{16}wL \\
 V_2 & \dots \dots \dots = \frac{9}{16}wL \\
 M_m \text{ [} @ x = \frac{7L}{16} \text{]} & \dots \dots \dots = \frac{49}{512}wL^2 \\
 M_1 \text{ [} @ R_2 \text{]} & \dots \dots \dots = -\frac{1}{16}wL^2 \\
 Mx \text{ [} @ x < L \text{]} & \dots \dots \dots = \frac{wx}{16}(7L - 8x) \\
 Dm \text{ [} @ x = 0.472L \text{]} & \dots \dots \dots = \frac{0.0092wL^4}{EI}
 \end{aligned}$$



Eq 511-32

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{M_1}{L_1} + \frac{wL_1}{2} \\
 R_2 & \dots \dots \dots = wL_1 + wL_2 - R_1 - R_3 \\
 R_3 = V_4 & \dots \dots \dots = \frac{M_1}{L_2} + \frac{wL_2}{2} \\
 V_2 & \dots \dots \dots = wL_1 - R_1 \\
 V_3 & \dots \dots \dots = wL_2 - R_3 \\
 M_1 & \dots \dots \dots = -\frac{wL_2^3 + wL_1^3}{8(L_1 + L_2)} \\
 Mx \text{ [} @ x < L_1 \text{ max. } @ x = \frac{R_1}{w} \text{]} & \dots \dots \dots = R_1x - \frac{wx^2}{2} \\
 Mx_1 \text{ [} @ x_1 < L_2 \text{ max. } @ x_1 = \frac{R_3}{w} \text{]} & \dots \dots \dots = R_3x_1 - \frac{wx_1^2}{2}
 \end{aligned}$$



Eq 511-33

$$R_1 = R_4 = V_1 = V_6 = \frac{4wL}{10}$$

$$R_2 = R_3 = \frac{11wL}{10}$$

$$V_2 = V_5 = \frac{6wL}{10}$$

$$V_3 = V_4 = \frac{wL}{2}$$

$$\text{Max. Pos. Mom. } M_1 \text{ [at } x = \frac{4L}{10}] = \frac{2wL^2}{25}$$

$$\text{Max. Neg. Mom. } M_2 \text{ [at } x = L] = -\frac{wL^2}{10}$$

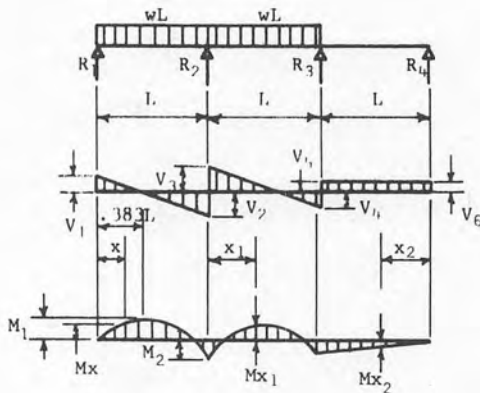
$$M_x \text{ [at } x < L \text{ max. at } x = \frac{4L}{10}] = \frac{4wLx}{10} - \frac{wx^2}{2}$$

$$M_{x_1} \text{ [at } x_1 < L \text{ max. at } x_1 = L/2] = \frac{wLx_1}{2} - \frac{wL^2}{10} - \frac{wx_1^2}{2}$$

$$D_1 = D_m = \frac{4wL^4}{581EI}$$

$$D_2 = \frac{wL^4}{1920EI}$$

Eq 511-34



$$R_1 = V_1 = 0.383wL$$

$$R_2 = 1.20wL$$

$$R_3 = 0.450wL$$

$$R_4 = -0.033wL$$

$$V_2 = 0.617wL$$

$$V_3 = 0.583wL$$

$$V_4 = 0.417wL$$

$$V_5 = V_6 = 0.033wL$$

$$\text{Max. Neg. Mom. } M_2 \text{ [at } x = L] = -0.1167wL^2$$

$$\text{Max. Pos. Mom. } M_1 \text{ [at } x = 0.383L] = 0.0735wL^2$$

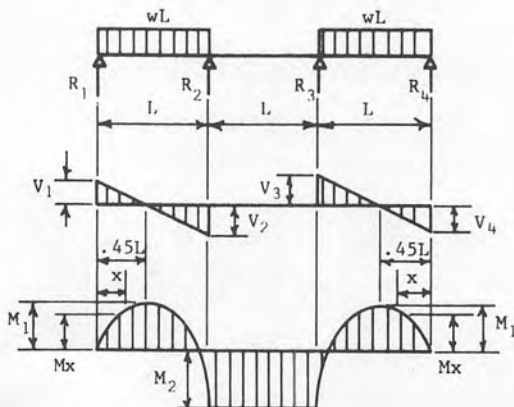
$$M_x \text{ [at } x < L \text{ max. at } x = 0.383L] = 0.383wLx - \frac{wx^2}{2}$$

$$M_{x_1} \text{ [at } x_1 < L \text{ max. at } x_1 = 0.583L] = 0.583wLx_1 - 0.1167wL^2 - \frac{wx_1^2}{2}$$

$$M_{x_2} \text{ [at } x_2 < L] = -0.033wLx_2$$

$$D_m \text{ [at } x = 0.430L] = \frac{0.0059wL^4}{EI}$$

Eq 511-35



$$R_1 = R_4 = V_1 = V_4 = 0.450wL$$

$$R_2 = R_3 = V_2 = V_3 = 0.550wL$$

$$\text{Max. Neg. Mom. } M_2 \text{ [at } x = L] = -0.05wL^2$$

$$\text{Max. Pos. Mom. } M_1 \text{ [at } x = 0.450L] = 0.1013wL^2$$

$$M_x \text{ [at } x < L] = 0.450wLx - \frac{wx^2}{2}$$

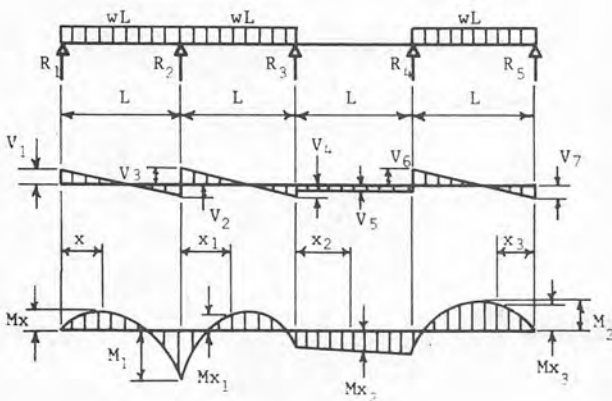
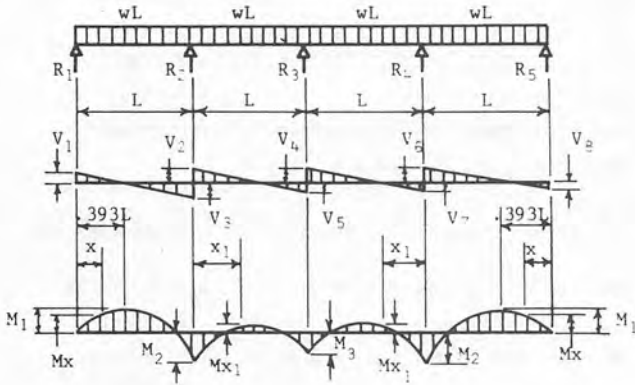
$$D_m \text{ [at } x = 0.479L] = \frac{0.0099wL^4}{EI}$$

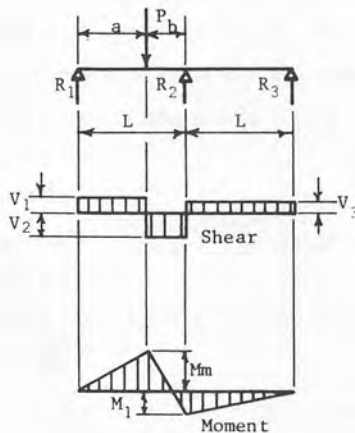
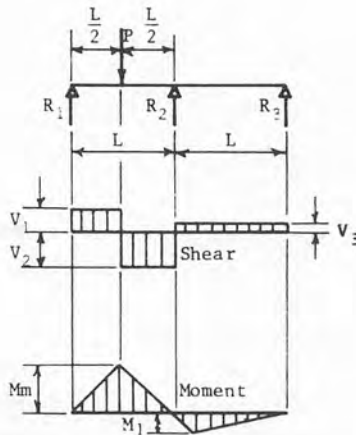
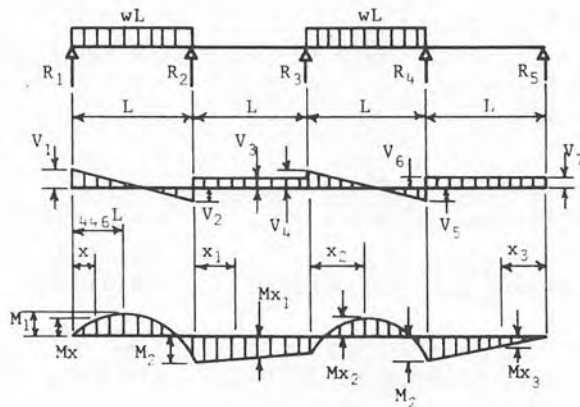
Eq 511-36

$$\begin{aligned}
 R_1 = R_5 = V_1 = V_8 & \dots = 0.393wL \\
 R_2 = R_4 & \dots = 1.143wL \\
 R_3 & \dots = 0.928wL \\
 V_2 = V_7 & \dots = 0.536wL \\
 V_3 = V_6 & \dots = 0.607wL \\
 V_4 = V_5 & \dots = 0.464wL \\
 \text{Max. Pos. Mom. } M_1 \text{ } [@ x = 0.393L] & \dots = 0.0772wL^2 \\
 \text{Max. Neg. Mom. } M_2 \text{ } [@ x = L] & \dots = -0.1071wL^2 \\
 M_3 & \dots = -0.0364wL^2 \\
 Mx \text{ } [@ x < L \text{ max. } @ x = 0.393L] & \dots = 0.393wLx - \frac{wx^2}{2} \\
 Mx_1 \text{ } [@ x_1 < L \text{ max. } @ x_1 = 0.536L] & \dots = 0.536wLx_1 - 0.1071wL^2 - \frac{wx_1^2}{2} \\
 Dm \text{ } [@ x = 0.440L] & \dots = \frac{0.0065wL^4}{EI}
 \end{aligned}$$

Eq 511-37

$$\begin{aligned}
 R_1 = V_1 & \dots = 0.380wL \\
 R_2 & \dots = 1.223wL \\
 R_3 & \dots = 0.357wL \\
 R_4 & \dots = 0.598wL \\
 R_5 = V_7 & \dots = 0.442wL \\
 V_2 & \dots = 0.620wL \\
 V_3 & \dots = 0.603wL \\
 V_4 & \dots = 0.397wL \\
 V_5 & \dots = 0.040wL \\
 V_6 & \dots = 0.558wL \\
 \text{Max. Pos. Mom. } M_2 \text{ } [@ x_3 = 0.442L] & \dots = 0.0977wL^2 \\
 \text{Max. Neg. Mom. } M_1 \text{ } [@ x = L] & \dots = -0.1205wL^2 \\
 Mx \text{ } [@ x < L \text{ max. } @ x = 0.380L] & \dots = 0.380wLx - \frac{wx^2}{2} \\
 Mx_1 \text{ } [@ x_1 < L \text{ max. } @ x_1 = 0.603L] & \dots = 0.603wLx_1 - 0.1205wL^2 - \frac{wx_1^2}{2} \\
 Mx_2 \text{ } [@ x_2 < L \text{ max. } @ x_2 = L] & \dots = -0.04wLx_2 - 0.0179wL^2 \\
 Mx_3 \text{ } [@ x_3 < L \text{ max. } @ x_3 = 0.442L] & \dots = 0.442wLx_3 - \frac{wx_3^2}{2} \\
 Dm \text{ } [@ x = 0.475L] & \dots = \frac{0.0094wL^4}{EI}
 \end{aligned}$$





Eq 511-38

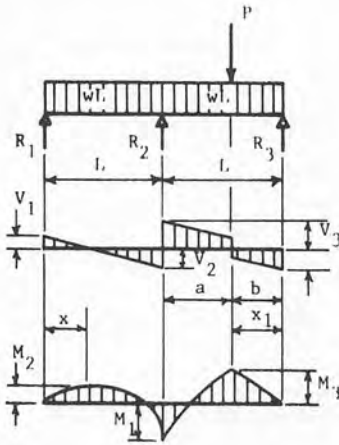
$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = 0.446wL \\
 R_2 = R_4 & \dots \dots \dots = 0.572wL \\
 R_3 & \dots \dots \dots = 0.464wL \\
 R_5 & \dots \dots \dots = -0.054wL \\
 V_2 & \dots \dots \dots = 0.554wL \\
 V_3 & \dots \dots \dots = 0.018wL \\
 V_4 & \dots \dots \dots = 0.482wL \\
 V_5 & \dots \dots \dots = 0.518wL \\
 V_6 = V_7 & \dots \dots \dots = 0.054wL \\
 \text{Max. Pos. Mom. } M_1 \text{ [} @ x = 0.446L \text{]} & \dots \dots \dots = 0.0996wL^2 \\
 \text{Max. Neg. Mom. } M_2 \text{ [} @ x = L \text{ and } @ x_2 = L \text{]} & \dots \dots \dots = -0.0536wL^2 \\
 Mx \text{ [} @ x < L \text{ max. } @ x = 0.446L \text{]} & \dots \dots \dots = 0.446wLx - \frac{wx^2}{2} \\
 Mx_1 \text{ [} @ x_1 < L \text{ max. } @ x_1 = 0 \text{]} & \dots \dots \dots = 0.018wLx_1 - 0.0536wL^2 \\
 Mx_2 \text{ [} @ x_2 < L \text{ max. } @ x_2 = 0.482L \text{]} & \dots \dots \dots = 0.482wLx_2 - \frac{0.0357wL^2}{2} - \frac{wx_2^2}{2} \\
 Mx_3 \text{ [} @ x_3 < L \text{ max. } @ x_3 = L \text{]} & \dots \dots \dots = -0.054wLx_3 \\
 Dm \text{ [} @ x = 0.477L \text{]} & \dots \dots \dots = \frac{0.0097wL^4}{EI}
 \end{aligned}$$

Eq 511-39

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{13}{32} P \\
 R_2 = V_2 + V_3 & \dots \dots \dots = \frac{11}{16} P \\
 R_3 = V_3 & \dots \dots \dots = -\frac{3}{32} P \\
 V_2 & \dots \dots \dots = \frac{19}{32} P \\
 Mm \text{ [} @ \text{ load]} & \dots \dots \dots = \frac{13}{64} PL \\
 M_1 \text{ [} @ R_2 \text{]} & \dots \dots \dots = -\frac{3}{32} PL
 \end{aligned}$$

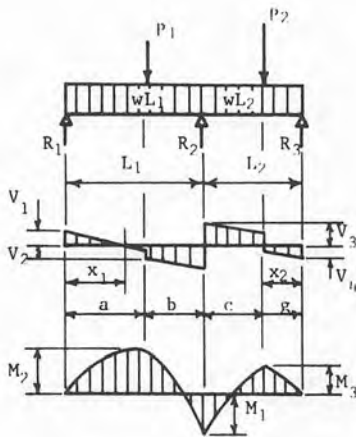
Eq 511-40

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{Pb}{4L^3}(4L^2 - a(L + a)) \\
 R_2 = V_2 + V_3 & \dots \dots \dots = \frac{Pa}{2L^3}(2L^2 + b(L + a)) \\
 R_3 = V_3 & \dots \dots \dots = -\frac{Pab}{4L^3}(L + a) \\
 V_2 & \dots \dots \dots = \frac{Pa}{4L^3}(4L^2 + b(L + a)) \\
 Mm \text{ [} @ \text{ load]} & \dots \dots \dots = \frac{Pab}{4L^3}(4L^2 - a(L + a)) \\
 M_1 \text{ [} @ R_2 \text{]} & \dots \dots \dots = -\frac{Pab}{4L^2}(L + a)
 \end{aligned}$$



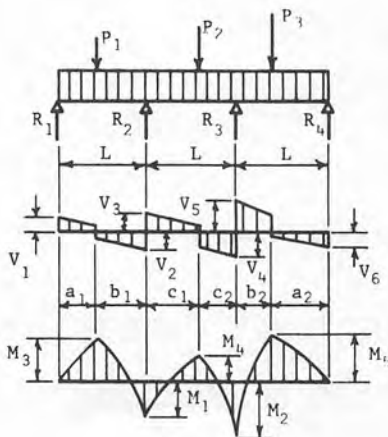
Eq 511-44

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{M_1}{L} - \frac{wL}{2} \\
 R_2 & \dots \dots \dots = 2wL + P - R_1 - R_3 \\
 R_3 = V_4 & \dots \dots \dots = \frac{M_1}{L} + \frac{Pa}{L} + \frac{wL}{2} \\
 V_2 & \dots \dots \dots = wL - R_1 \\
 V_3 & \dots \dots \dots = wL + P - R_3 \\
 M_1 & \dots \dots \dots = -\frac{wL^2}{8} - \frac{Pb(L^2 - b^2)}{4L^2} \\
 M_2 \text{ [} @ \ x = \frac{R_1}{w} \text{]} & \dots \dots \dots = R_1x - \frac{wx^2}{2} \\
 M_3 \text{ [} @ \ x_1 = \frac{R_3}{w} \text{ when } R_3 < wb \text{]} & = R_3x_1 - \frac{wx_1^2}{2}
 \end{aligned}$$



Eq 511-45

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{M_1 + P_1b}{L_1} + \frac{wL_1}{2} \\
 R_2 & \dots \dots \dots = wL_1 + wL_2 + P_1 + P_2 - R_1 - R_3 \\
 R_3 = V_4 & \dots \dots \dots = \frac{M_1 + P_2c}{L_2} + \frac{wL_2}{2} \\
 V_2 & \dots \dots \dots = wL_1 + P_1 - R_1 \\
 V_3 & \dots \dots \dots = wL_2 + P_2 - R_3 \\
 M_1 & \dots \dots \dots = -\left[\frac{4P_1L_1^2(\frac{a}{L_1} - \frac{a^3}{L_1^3}) + 4P_2L_2^2(\frac{g}{L_2} - \frac{g^3}{L_2^3}) + wL_1^3 + wL_2^3}{8(L_1 + L_2)} \right] \\
 M_2 \text{ [} @ \ \frac{R_1}{w} \text{ when } R_1 \leq wa \text{]} & \dots \dots = R_1x_1 - \frac{wx_1^2}{2} \\
 M_3 \text{ [} @ \ \frac{R_3}{w} \text{ when } R_3 \leq wg \text{]} & \dots \dots = R_3x_2 - \frac{wx_2^2}{2}
 \end{aligned}$$

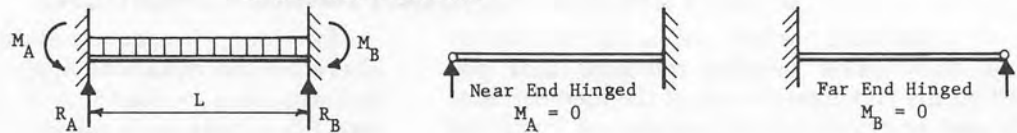


Eq 511-46

$$\begin{aligned}
 R_1 = V_1 & \dots \dots \dots = \frac{wL}{2} + \frac{M_1 + P_1b_1}{L} \\
 R_2 & \dots \dots \dots = 2wL + \frac{M_2 - 2R_1L + P_2c_2 + P_1(L + b_1)}{L} \\
 R_3 & \dots \dots \dots = 2wL + \frac{M_1 - R_4L + P_2c_1 + P_3(L + b_2)}{L} \\
 R_4 = V_6 & \dots \dots \dots = \frac{wL}{2} + \frac{M_2 + P_3b_2}{L} \\
 V_2 & \dots \dots \dots = P_1 + wL - R_1 \\
 V_3 & \dots \dots \dots = R_2 - V_2 \\
 V_4 & \dots \dots \dots = R_3 - V_5 \\
 V_5 & \dots \dots \dots = P_3 + wL - R_4 \\
 M_1 & \dots \dots \dots = \frac{-4P_1a_1b_1(L + a_1) - P_2c_1c_2(7L - 5c_1) + P_3b_2a_2(L + a_2)}{15L^2} - \frac{wL^2}{10} \\
 M_2 & \dots \dots \dots = \frac{P_1a_1b_1(L + a_1) - P_2c_1c_2(2L + 5c) - 4P_3b_2a_2(L + a_2)}{15L^2} - \frac{wL^2}{10} \\
 M_3 & \dots \dots \dots = R_1a_1 - \frac{wa_1^2}{2} \\
 M_4 & \dots \dots \dots = M_1 + V_3c_1 - \frac{wc_1^2}{2} \\
 M_5 & \dots \dots \dots = R_4a_2 - \frac{wa_2^2}{2}
 \end{aligned}$$

Fixed-End Beams

Eq 511-47



Both Ends Fixed

Fig #	M_A	M_B	R_A	R_B
1	$\frac{wL^2}{12}$	$\frac{wL^2}{12}$	$wL/2$	$wL/2$
2	$\frac{w}{12L^2} [(b+c)^3 (4L-3b-3c) - c^3 (4L-3c)]$	$\frac{w}{12L^2} [(a+b)^3 (4L-3a-3b) - a^3 (4L-3a)]$	$\frac{M_A - M_B + wb(c+b/2)}{L}$	$\frac{M_B - M_A + wb(a+b/2)}{L}$
3	$\frac{wa^2}{12L^2} (3a^2 - 8aL + 6L^2)$	$\frac{wb^2}{12L^2} (4L-3a)$	$\frac{M_A - M_B + wa(L-a/2)}{L}$	$\frac{M_B - M_A + wb(L-b/2)}{L}$
4	$\frac{wa^2}{6L} (3L-2a)$	$\frac{wb^2}{6L} (3L-2a)$	wa	wb
5	$\frac{wL^2}{20}$	$\frac{wL^2}{30}$	$\frac{7wL}{20}$	$\frac{3wL}{20}$
6	$\frac{wa^2}{60L^2} (3a^2 - 10aL + 10L^2)$	$\frac{wb^2}{60L^2} (5L-3a)$	$\frac{M_A - M_B + \frac{wa}{2}(L-a/3)}{L}$	$\frac{M_B - M_A + \frac{wb}{2}(L-b/3)}{L}$
7	$\frac{wa^2}{30L^2} (10L^2 - 15aL + 6a^2)$	$\frac{wb^2}{20L^2} (5L-4a)$	$\frac{M_A - M_B + \frac{wa}{2}(L-2a/3)}{L}$	$\frac{M_B - M_A + \frac{wb}{2}(L-b/3)}{L}$
8	$\frac{wL^2}{15}$	$\frac{wL^2}{15}$	$wL/3$	$wL/3$
9	$\frac{Pab^2}{L^2}$	$\frac{Pa^2b}{L^2}$	$\frac{Pb + M_A - M_B}{L}$	$\frac{M_B - M_A + Pa}{L}$
10	$\frac{Pa(L-a)}{L}$	$\frac{Pa(L-a)}{L}$	P	P
11	$\frac{5PL}{16}$	$\frac{5PL}{16}$	$3P/2$	$3P/2$

 Near End Hinged, $M_A = 0$

Fig #	M_A	M_B	R_A	R_B
6	0	$\frac{wa^2}{120L^2} (10L^2 - 3a^2)$	$-\frac{M_B + \frac{wa}{2}(L-a/3)}{L}$	$\frac{M_B + wa^2/6}{L}$
7	0	$\frac{wa^2}{30L^2} (5L^2 - 3a^2)$	$-\frac{M_B + \frac{wa}{2}(L-2a/3)}{L}$	$\frac{M_B + wa^2/3}{L}$
3	0	$\frac{wa^2}{8L^2} (2L^2 - a^2)$	$-\frac{M_B + (wa)(L-a/2)}{L}$	$\frac{M_B + wa^2/2}{L}$

 Far End Hinged, $M_B = 0$

Fig #	M_A	M_B	R_A	R_B
1	$wL^2/8$	0	$5wL/8$	$3wL/8$
2	$\frac{w}{8L^2} (b^2 + 2cb) (2L^2 - 2c^2 - 2cb - b^2)$	0	$\frac{M_A + wb(c+b/2)}{L}$	$-\frac{M_A + wb(a+b/2)}{L}$
3	$\frac{wa^2}{8L^2} (2L-a)^2$	0	$\frac{M_A + wa(L-a/2)}{L}$	$-\frac{M_A + wa^2/2}{L}$
4	$\frac{wa^2}{4L} (3L-2a)$	0	$\frac{M_A + waL}{L}$	$\frac{waL - M_A}{L}$
5	$wL^2/15$	0	$2wL/5$	$wL/10$
6	$\frac{wa^2}{120L^2} (20L^2 - 15aL + 3a^2)$	0	$\frac{M_A + \frac{wa}{2}(L-a/3)}{L}$	$-\frac{M_A + wa^2/6}{L}$
7	$\frac{wa^2}{120L^2} (40L^2 - 45aL + 12a^2)$	0	$\frac{M_A + \frac{wa}{2}(L-2a/3)}{L}$	$-\frac{M_A + wa^2/3}{L}$
8	$wL^2/10$	0	$\frac{M_A + wL^2/3}{L}$	$-\frac{M_A + wL^2/3}{L}$
9	$\frac{Pab}{L^2} (b+a/2)$	0	$\frac{Pb + M_A}{L}$	$\frac{Pa - M_A}{L}$
10	$\frac{3Pa}{2L} (L-a)$	0	$\frac{M_A + PL}{L}$	$-\frac{M_A + PL}{L}$
11	$\frac{15PL}{32}$	0	$\frac{M_A + 3PL/2}{L}$	$-\frac{M_A + 3PL/2}{L}$

CHAPTER 512 GABLE FRAME FORMULAS

Loads shown are positive and cause positive reactions. They cause bending moments that are plotted on the compression side of the member. Moments and reactions from superimposed loads are algebraically additive.

Each point on the frame has two coordinates. For symmetrical loads, a point on the rafter is x from the left, x' from the ridge; a point on a leg is y from the base, y' from the haunch. For unsymmetrical loads use x_1 , x'_1 , x_2 , etc.

Two-hinge frames are statically indeterminate. Therefore the equations apply only to frames with uniform cross sections in both legs and in both rafters. Some increase in member size at the haunches and ridge, which are assumed rigid, will have only a minor effect on moments and reactions.

Three-hinge frames are statically determinate. Therefore the members need not be of uniform cross section—tapering does not affect moments or reactions.

Frame Coefficients for Eq 512.1 - 512.7

$$\begin{aligned} k & \dots \dots \dots = I_2 h / I_1 s \\ \psi & \dots \dots \dots = f / h \\ m & \dots \dots \dots = 1 + \psi \\ B & \dots \dots \dots = 2(k + 1) + m \\ C & \dots \dots \dots = 1 + 2m \\ N & \dots \dots \dots = B + mC \\ n & = L/2 = x + x' = x_1 + x'_1 \end{aligned}$$

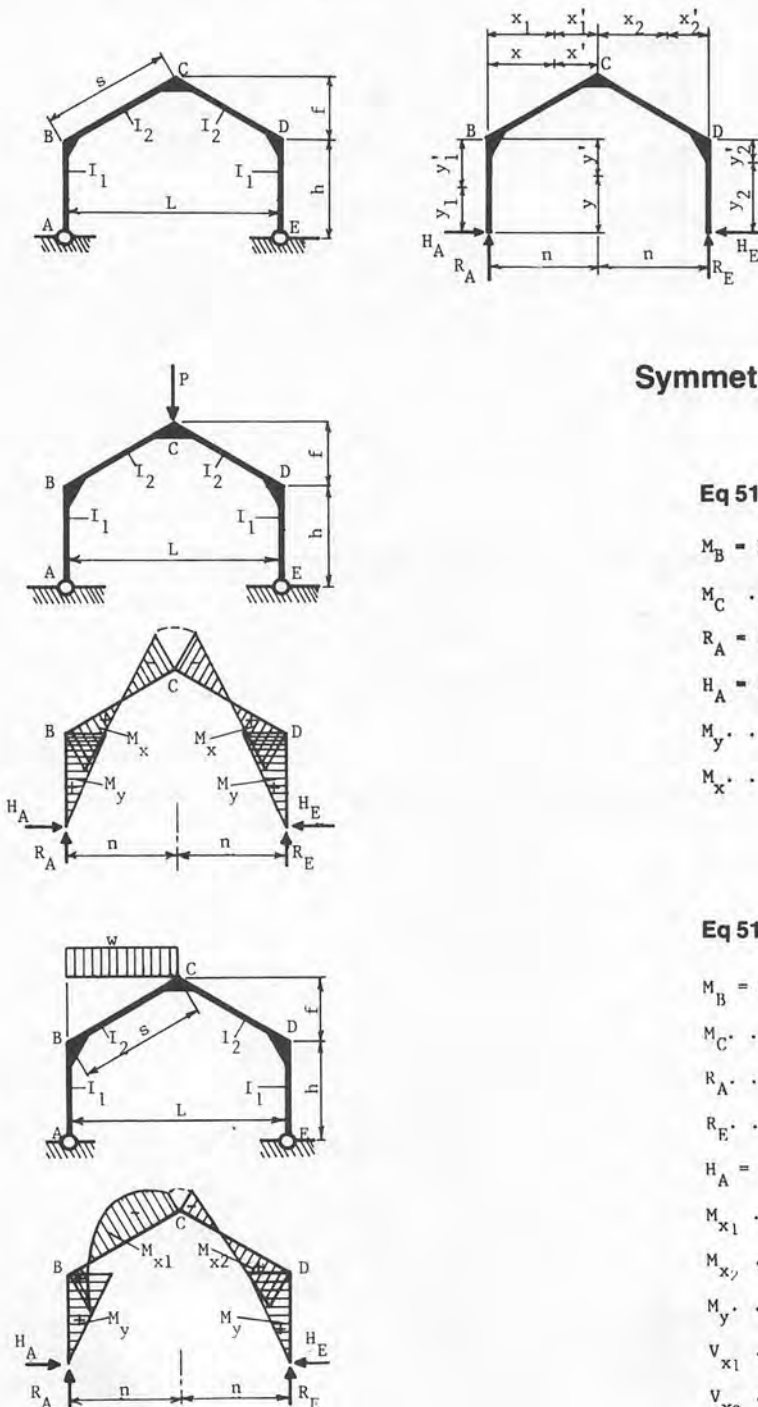
Symmetrical, 2-hinged, vertical legs.

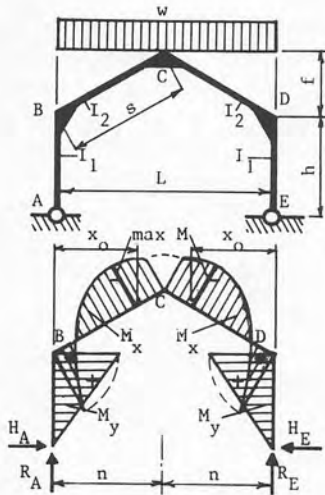
Eq 512.1

$$\begin{aligned} M_B &= M_D \dots \dots = PLC/4N \\ M_C &\dots \dots \dots = -PLB/4N \\ R_A &= R_E \dots \dots = P/2 \\ H_A &= H_E \dots \dots = M_B/h \\ M_y &\dots \dots \dots = yM_B/h \\ M_x &\dots \dots \dots = x'M_B/n + xM_C/n \end{aligned}$$

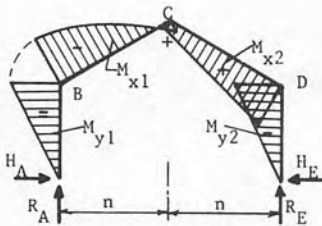
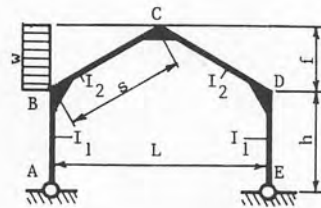
Eq 512.2

$$\begin{aligned} M_B &= M_D \dots \dots = wL^2(3+5m)/32N \\ M_C &\dots \dots \dots = -wL^2/16 + mM_B \\ R_A &\dots \dots \dots = 3wL/8 \\ R_E &\dots \dots \dots = wL/8 \\ H_A &= H_E \dots \dots = M_B/h \\ M_{x_1} &\dots \dots \dots = -wx_1 x'_1/2 + x'_1 M_B/n + x_1 M_C/n \\ M_{x_2} &\dots \dots \dots = x'_2 M_C/n + x_2 M_D/n \\ M_y &\dots \dots \dots = yM_B/h \\ v_{x_1} &\dots \dots \dots = -wL^2(\frac{1}{2} - \frac{x_1}{n})/4s + (M_C - M_B)/s \\ v_{x_2} &\dots \dots \dots = (M_D - M_C)/s \end{aligned}$$




Eq 512.3

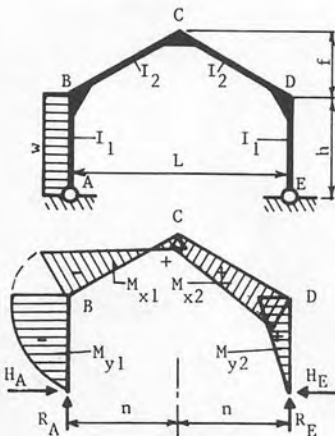
$$\begin{aligned}
 M_B = M_D & \dots = wL^2(3+5m)/16N \\
 M_C & \dots = -wL^2/8 + mM_B \\
 R_A = R_E & \dots = wL/2 \\
 H_A = H_E & \dots = M_B/h \\
 M_x & \dots = -wx x'/2 + x'M_B/n + xM_C/n \\
 M_y & \dots = yM_B/h \\
 V_x & \dots = -wL^2(\frac{1}{2} - \frac{x}{n})/4s + (M_C - M_B)/s \\
 x_0 & \dots = L/4 + (M_B - M_C)/wn
 \end{aligned}$$

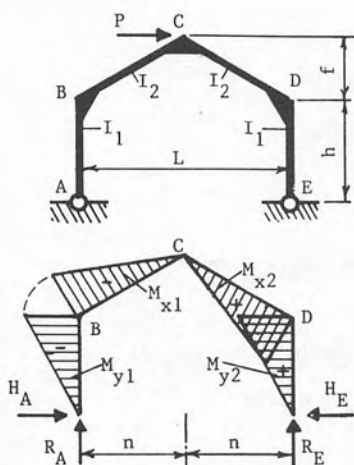

Eq 512.4

$$\begin{aligned}
 X & \dots = wf^2(C+m)/8N \\
 M_B & \dots = -X - wfh/2 \\
 M_C & \dots = wf^2/4 + mX \\
 M_D & \dots = -X + wfh/2 \\
 R_A = -R_E & \dots = -wf(h+f/2)/L \\
 H_A & \dots = -x/h - wf/2 \\
 H_E & \dots = -x/h + wf/2 \\
 M_{x1} & \dots = -wf^2x_1 x'_1/2n + x'_1 M_B/n + x_1 M_C/n \\
 M_{x2} & \dots = x'_2 M_C/n + x_2 M_D/n \\
 M_{y1} & \dots = y_1 M_B/h \\
 M_{y2} & \dots = y_2 M_D/h \\
 V_{x1} & \dots = -wf^2(\frac{1}{2} - \frac{x_1}{n})/sn + (M_C - M_B)/s
 \end{aligned}$$

Eq 512.5

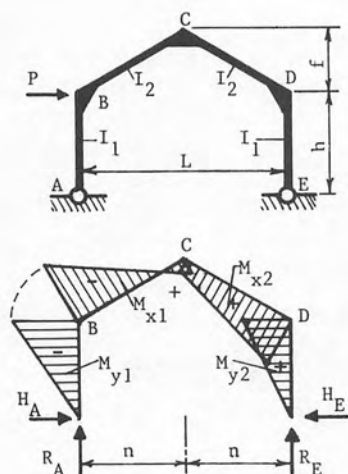
$$\begin{aligned}
 M_B & \dots = -wh^2/2 + M_D \\
 M_C & \dots = -wh^2/4 + mM_D \\
 M_D & \dots = (wh^2)[2(B+C) + k]/8N \\
 R_A = -R_E & \dots = -wh^2/2L \\
 H_A & \dots = -(wh - H_E) \\
 H_E & \dots = M_D/h \\
 M_{x1} & \dots = x'_1 M_B/n + x_1 M_C/n \\
 M_{x2} & \dots = x'_2 M_C/n + x_2 M_D/n \\
 M_{y1} & \dots = -wy_1 y'_1/2 + y_1 M_B/h \\
 M_{y2} & \dots = y_2 M_D/h
 \end{aligned}$$





Eq 512.6

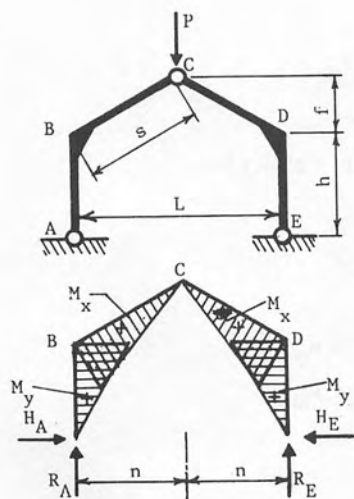
$$\begin{aligned} M_B &= -M_D \dots = -Ph/2 \\ M_C &\dots\dots\dots = 0 \\ R_A &= -R_E \dots\dots = -Phm/L \\ H_A &= -H_E \dots\dots = -P/2 \\ M_{x1} &= -M_{x2} \dots\dots = -Phx'_1/L \\ M_{y1} &= -M_{y2} = -Py_1/2 \end{aligned}$$



Eq 512.7

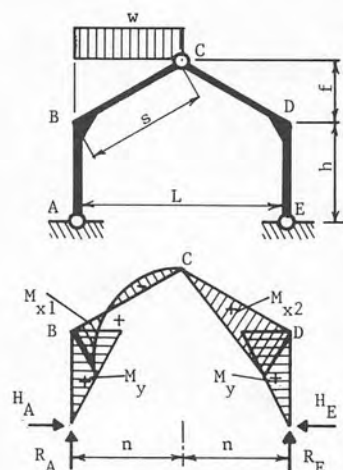
$$\begin{aligned} M_B &\dots\dots\dots = -Ph + M_D \\ M_C &\dots\dots\dots = -Ph/2 + mM_D \\ M_D &\dots\dots\dots = Ph(B+C)/2N \\ R_A &= -R_E \dots\dots = -Ph/L \\ H_A &\dots\dots\dots = -(P - H_E) \\ H_E &\dots\dots\dots = M_D/h \\ M_{x1} &\dots\dots\dots = x'_1 M_B/n + x'_1 M_C/n \\ M_{x2} &\dots\dots\dots = x'_2 M_C/n + x'_2 M_D/n \\ M_{y1} &\dots\dots\dots = y_1 M_B/h \\ M_{y2} &\dots\dots\dots = y_2 M_D/h \end{aligned}$$

Symmetrical, 3-hinged, vertical legs.

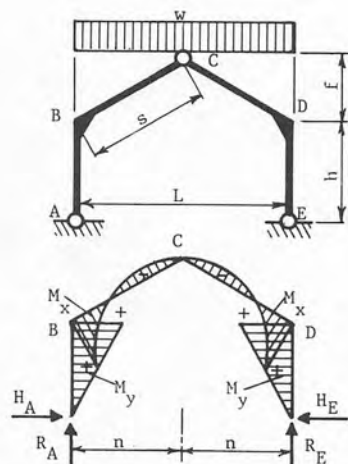


Eq 512.8

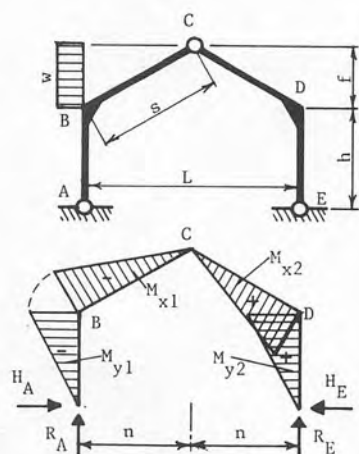
$$\begin{aligned} M_B &= M_D \dots\dots = Plh/4(f+h) \\ R_A &= R_E \dots\dots = P/2 \\ H_A &= H_E \dots\dots = M_B/h \\ M_x &\dots\dots\dots = x' M_B/n \\ M_y &\dots\dots\dots = y M_B/h \end{aligned}$$


Eq 512.9

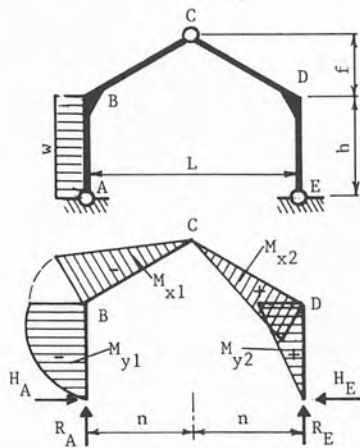
$$\begin{aligned} M_B = M_D & \dots = wL^2h/16(f+h) \\ R_A & \dots = 3wL/8 \\ R_E & \dots = wL/8 \\ H_A = H_E & \dots = M_B/h \\ M_{x1} & \dots = -wx_1x_1'/2 + x_1'M_B/n \\ M_{x2} & \dots = x_2'M_D/n \\ M_y & \dots = yM_B/h \end{aligned}$$


Eq 512.10

$$\begin{aligned} M_B = M_D & \dots = wL^2h/8(f+h) \\ R_A = R_E & \dots = wL/2 \\ H_A = H_E & \dots = M_B/h \\ M_x & \dots = -wx_1x_1'/2 + x_1'M_B/n \\ M_y & \dots = yM_B/h \end{aligned}$$


Eq 512.11

$$\begin{aligned} M_B & \dots = -wf h(3f/4 + h/2)/(f+h) \\ M_D & \dots = wf h(3f/4 + h/2)/(f+h) + wf h \\ R_A = -R_E & \dots = -wf(h + f/2)/L \\ H_A & \dots = M_B/h \\ H_E & \dots = H_A + wf \\ M_{x1} & \dots = -wf^2x_1x_1'/2n^2 + x_1'M_B/n \\ M_{x2} & \dots = x_2'M_D/n \\ M_{y1} & \dots = y_1'M_B/h \\ M_{y2} & \dots = y_2'M_C/h \end{aligned}$$



Eq 512.12

$$M_B \dots \dots = -wh^2(3h/4 + f)/(f+h)$$

$$M_D \dots \dots = wh^3/4(f+h)$$

$$R_A = -R_E \dots = -wh^2/2L$$

$$H_A \dots \dots = M_B/h - wh/2$$

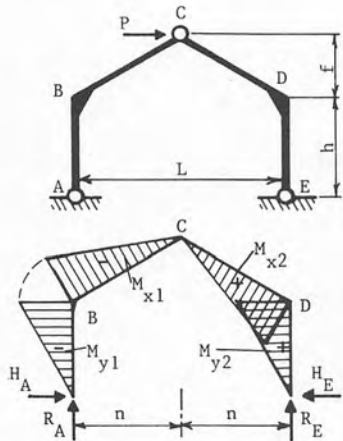
$$H_E \dots \dots = wh + H_A$$

$$M_{x1} \dots \dots = x'_1 M_B/n$$

$$M_{x2} \dots \dots = x_2 M_D/n$$

$$M_{y1} \dots \dots = -wy_1 y'_1/2 + y_1 M_B/h$$

$$M_{y2} \dots \dots = y_2 M_D/h$$



Eq 512.13

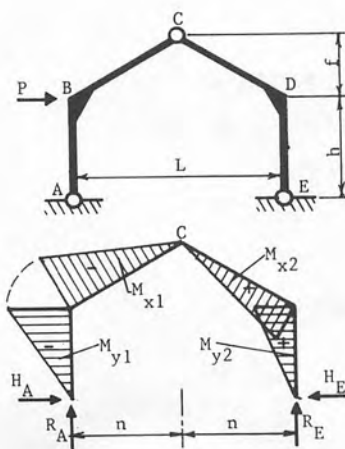
$$M_B = -M_D \dots = -Ph/2$$

$$R_A = -R_E \dots = -P(f+h)/L$$

$$H_A = -H_E \dots = -P/2$$

$$M_{x1} = -M_{x2} \dots = -Phx'_1/L$$

$$M_{y1} = -M_{y2} \dots = -Py_1/2$$



Eq 512.14

$$M_B \dots \dots = -Ph(f + h/2)/(f+h)$$

$$M_D \dots \dots = Ph^2/2(f+h)$$

$$R_A = -R_E \dots = -Ph/L$$

$$H_A \dots \dots = M_B/h$$

$$H_E \dots \dots = P + H_A$$

$$M_{x1} \dots \dots = x'_1 M_B/n$$

$$M_{x2} \dots \dots = x_2 M_D/n$$

$$M_{y1} \dots \dots = y_1 M_B/h$$

$$M_{y2} \dots \dots = y_2 M_D/h$$

CHAPTER 513 PIPE, SQUARE TUBING, AND I-BEAM PROPERTIES

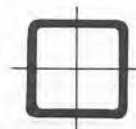
American Institute of Steel Construction

Table 513-1. Structural pipe.



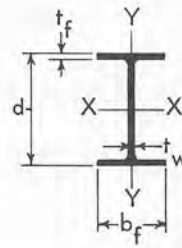
Dimensions					Properties		
Nominal dia in.	Outside dia in.	Inside dia in.	Thick-ness in.	lb/ft lb	I in ⁴	A in ²	r in.
Standard Weight, ASA No. 40					40		
3/8	.675	.493	.091	.57	.007	.167	.21
1/2	.840	.622	.109	.85	.017	.250	.26
3/4	1.050	.824	.113	1.13	.037	.333	.33
1	1.315	1.049	.133	1.68	.087	.494	.42
1 1/4	1.660	1.380	.140	2.27	.195	.669	.54
1 1/2	1.900	1.610	.145	2.72	.310	.799	.62
2	2.375	2.067	.154	3.65	.666	1.075	.79
2 1/2	2.875	2.469	.203	5.79	1.530	1.704	.95
3	3.500	3.068	.216	7.58	3.017	2.228	1.16
3 1/2	4.000	3.548	.226	9.11	4.788	2.680	1.34
4	4.500	4.026	.237	10.79	7.233	3.174	1.51
5	5.563	5.047	.258	14.62	15.16	4.300	1.88
6	6.625	6.065	.280	18.97	28.14	5.581	2.25
Extra strong, ASA No. 80							
2	2.375	1.939	.218	5.02	.868	1.477	.77
2 1/2	2.875	2.323	.276	7.66	1.924	2.254	.92
3	3.500	2.900	.300	10.25	3.894	3.016	1.14
3 1/2	4.000	3.364	.318	12.51	6.280	3.678	1.31
4	4.500	3.826	.337	14.98	9.610	4.407	1.48
5	5.563	4.813	.375	20.78	20.67	6.112	1.84
6	6.625	5.761	.432	28.57	40.49	8.405	2.20
Double Extra Strong							
2	2.375	1.503	.436	9.03	1.311	2.656	.70
2 1/2	2.875	1.771	.552	13.70	2.871	4.028	.84
3	3.500	2.300	.600	18.58	5.992	5.466	1.05
4	4.500	3.152	.674	27.54	15.28	8.101	1.37
5	5.563	4.063	.750	38.55	33.64	11.34	1.72
6	6.625	4.897	.864	53.16	66.33	15.64	2.06

Table 513-2. Structural square tubing.



Dimensions			Properties			
Nominal size in.	Wall thickness in.	lb/ft lb	Area in ²	I in ⁴	S in ³	r in.
8x8						
	.500 1/2	47.35	13.93	124.1	31.02	2.98
	.375 3/8	36.83	10.83	101.5	25.37	3.06
	.312 5/16	31.24	9.189	88.10	22.02	3.10
	.250 1/4	25.44	7.482	73.83	18.35	3.13
7x7						
	.500 1/2	40.55	11.93	78.91	22.55	2.57
	.375 3/8	31.73	9.334	65.54	18.73	2.65
	.312 5/16	26.99	7.939	57.31	16.37	2.69
	.250 1/4	22.04	6.482	48.05	13.73	2.72
	.187 3/16	16.85	4.958	37.70	10.77	2.76
6x6						
	.500 1/2	34.48	10.14	48.38	16.13	2.18
	.375 3/8	27.04	7.954	40.44	13.48	2.25
	.312 5/16	23.02	6.772	35.47	11.82	2.29
	.250 1/4	18.82	5.535	29.85	9.948	2.32
	.187 3/16	14.41	4.238	23.50	7.832	2.35
5x5						
	.500 1/2	27.68	8.142	25.52	10.21	1.77
	.375 3/8	21.94	6.454	21.95	8.778	1.84
	.312 5/16	18.77	5.522	19.49	7.796	1.88
	.250 1/4	15.42	4.535	16.60	6.638	1.91
	.187 3/16	11.86	3.488	13.21	5.283	1.95
4x4						
	.375 3/8	16.84	4.954	10.15	5.076	1.43
	.312 5/16	14.52	4.272	9.203	4.602	1.47
	.250 1/4	12.02	3.535	7.988	3.994	1.50
	.187 3/16	9.31	2.738	6.468	3.234	1.54
3½x3½						
	.312 5/16	12.69	3.733	6.083	3.476	1.28
	.250 1/4	10.50	3.089	5.284	3.020	1.31
	.187 3/16	8.14	2.394	4.290	2.452	1.34
3x3						
	.312 5/16	10.57	3.108	3.566	2.378	1.07
	.250 1/4	8.80	2.589	3.151	2.101	1.10
	.187 3/16	6.86	2.019	2.598	1.732	1.13

Table 513-3. I-Beams, W & M shapes.



Name	Flange				Web thick- ness t _w	Elastic properties						Compact section criteria						
	Area A	Depth d	Width b _f	Thick- ness t _f		Axis X-X			Axis Y-Y			r _T	d A _f	b _f 2t _f	F _y '	d t _w	F _y ''	F _y '''
						I	S	r	I	S	r							
in ²	in.	in.	in.	in.	in.	in ⁴	in ³	in.	in ⁴	in ³	in.	in.			ksi		ksi	ksi
W 12x50	14.7	12.1	8.077	0.641	0.371	395	64.7	5.18	56.4	14.0	1.96	2.19	2.35	6.30	-	32.9	-	61.2
x45	13.2	12.0	8.042	0.576	0.336	351	58.2	5.15	50.0	12.4	1.94	2.18	2.60	6.98	55.9	35.9	-	51.3
x40	11.8	11.9	8.000	0.516	0.294	310	51.9	5.13	44.1	11.0	1.94	2.16	2.89	7.75	45.3	40.6	-	40.0
x36	10.6	12.2	6.565	0.540	0.305	281	46.0	5.15	25.5	7.77	1.55	1.77	3.45	6.08	-	40.1	-	41.0
x31	9.13	12.0	6.525	0.465	0.265	239	39.5	5.12	21.6	6.61	1.54	1.75	3.98	7.02	55.4	45.6	-	31.7
W 12x27	7.95	11.9	6.497	0.400	0.237	204	34.2	5.07	18.3	5.63	1.52	1.74	4.60	8.12	41.3	50.5	-	25.9
x22	6.47	12.3	4.030	0.424	0.260	156	25.3	4.91	4.64	2.31	0.84	1.03	7.20	4.75	-	47.3	-	29.5
x19	5.59	12.1	4.007	0.349	0.237	130	21.3	4.82	3.76	1.88	0.82	1.01	8.70	5.74	-	51.3	-	25.1
x16.5	4.87	12.0	4.000	0.269	0.230	105	17.6	4.65	2.88	1.44	0.77	0.97	11.2	7.43	49.3	52.2	62.4	24.3
x14	4.12	11.9	3.968	0.224	0.198	88.0	14.8	4.62	2.34	1.18	0.75	0.95	13.4	8.86	34.7	60.2	46.9	18.3
W 10x45	13.2	10.1	8.022	0.618	0.350	249	49.1	4.33	53.2	13.3	2.00	2.21	2.04	6.49	64.7	28.9	-	-
x39	11.5	9.94	7.990	0.528	0.318	210	42.2	4.27	44.9	11.2	1.98	2.19	2.36	7.57	47.6	31.3	-	-
x33	9.71	9.75	7.964	0.433	0.292	171	35.0	4.20	36.5	9.16	1.94	2.16	2.83	9.20	32.2	33.4	-	59.2
x29	8.54	10.2	5.799	0.500	0.289	158	30.8	4.30	16.3	5.61	1.38	1.57	3.52	5.80	-	35.4	-	52.8
x25	7.36	10.0	5.762	0.430	0.252	133	26.5	4.26	13.7	4.76	1.37	1.56	4.07	6.70	60.7	40.0	-	41.3
W 10x21	6.20	9.90	5.750	0.340	0.240	107	21.5	4.15	10.8	3.75	1.32	1.53	5.06	8.46	38.1	41.3	-	38.8
x19	5.61	10.2	4.020	0.394	0.250	96.3	18.8	4.14	4.28	2.13	0.87	1.05	6.47	5.10	-	41.0	-	39.3
x17	4.99	10.1	4.010	0.329	0.240	81.9	16.2	4.05	3.55	1.77	0.84	1.03	7.67	6.09	-	42.2	-	37.1
x15	4.41	10.0	4.000	0.269	0.230	68.9	13.8	3.95	2.88	1.44	0.80	1.00	9.29	7.43	49.3	43.5	-	34.9
x11.5	3.39	9.87	3.950	0.204	0.180	52.0	10.5	3.92	2.10	1.06	0.78	0.97	12.2	9.68	29.1	54.8	56.5	22.0
W 8x31	9.12	8.00	8.000	0.433	0.288	110	27.4	3.47	37.0	9.24	2.01	2.21	2.31	9.24	31.9	27.8	-	-
x28	8.23	8.06	6.540	0.463	0.285	97.8	24.3	3.45	21.6	6.61	1.62	1.80	2.66	7.06	54.6	28.3	-	-
x24	7.06	7.93	6.500	0.398	0.245	82.5	20.8	3.42	18.2	5.61	1.61	1.78	3.17	8.17	40.9	32.4	-	63.0
x20	5.89	8.14	5.268	0.378	0.248	69.4	17.0	3.43	9.22	3.50	1.25	1.42	4.09	6.97	56.1	32.8	-	61.3
W 8x17	5.01	8.00	5.250	0.308	0.230	56.6	14.1	3.36	7.44	2.83	1.22	1.40	4.95	8.52	37.5	34.8	-	54.6
x15	4.43	8.12	4.015	0.314	0.245	48.1	11.8	3.29	3.40	1.69	0.876	1.04	6.44	6.39	-	33.1	-	60.1
x13	3.83	8.00	4.000	0.254	0.230	39.6	9.90	3.21	2.72	1.36	0.842	1.02	7.87	7.87	43.9	34.8	-	54.6
x10	2.96	7.90	3.940	0.204	0.170	30.8	7.80	3.23	2.08	1.06	0.839	1.00	9.83	9.66	29.2	46.5	-	30.6
W 6x25	7.35	6.37	6.080	0.456	0.320	53.3	16.7	2.69	17.1	5.62	1.53	1.69	2.30	6.67	61.3	19.9	-	-
x20	5.88	6.20	6.018	0.367	0.258	41.5	13.4	2.66	13.3	4.43	1.51	1.66	2.81	8.20	40.5	24.0	-	-
x16	4.72	6.25	4.030	0.404	0.260	31.7	10.2	2.59	4.42	2.19	0.967	1.10	3.84	4.99	-	24.0	-	-
x12	3.54	6.00	4.000	0.279	0.230	21.7	7.25	2.48	2.98	1.49	0.918	1.07	5.38	7.17	53.0	26.1	-	-
x8.5	2.51	5.83	3.940	0.194	0.170	14.8	5.08	2.43	1.98	1.01	0.889	1.04	7.63	10.2	26.4	34.3	-	56.2
W 5x18.5	5.43	5.12	5.025	0.420	0.265	25.4	9.94	2.16	8.89	3.54	1.28	1.40	2.43	5.98	-	19.3	-	-
x16	4.70	5.00	5.000	0.360	0.240	21.3	8.53	2.13	7.51	3.00	1.26	1.39	2.78	6.94	56.5	20.8	-	-
W 4x13	3.82	4.16	4.060	0.345	0.280	11.3	5.45	1.72	3.76	1.85	0.991	1.11	2.97	5.88	-	14.9	-	-
M SHAPES																		
M 14x17.2	5.05	14.0	4.000	0.272	0.210	147	21.1	5.40	2.65	1.33	0.72	0.92	12.8	7.34	50.6	66.7	38.2	14.9
M 12x11.8	3.47	12.0	3.065	0.225	0.177	71.9	12.0	4.55	0.98	0.63	0.53	0.69	17.4	6.81	58.7	67.8	36.9	14.4
M 10x29.1	8.56	9.88	5.937	0.389	0.427	131	26.6	3.92	11.2	3.76	1.14	1.40	4.28	7.63	46.8	23.1	-	-
x22.9	6.73	9.88	5.752	0.389	0.242	117	23.6	4.16	10.0	3.48	1.22	1.40	4.42	7.39	49.8	40.8	-	39.6
x9	2.65	10.00	2.690	0.206	0.157	38.8	7.76	3.83	0.60	0.45	0.48	0.61	18.0	6.53	63.9	63.7	41.8	16.3
M 8x22.5	6.60	8.00	5.395	0.353	0.375	68.2	17.1	3.22	7.48	2.77	1.06	1.28	4.20	7.64	46.7	21.3	-	-
x18.5	5.44	8.00	5.250	0.353	0.230	62.0	15.5	3.38	6.82	2.60	1.12	1.28	4.32	7.44	49.3	34.8	-	54.6
x6.5	1.92	8.00	2.281	0.189	0.135	18.5	4.62	3.10	0.34	0.30	0.42	0.53	18.6	6.03	-	59.3	48.3	18.8
M 7x5.5	1.62	7.00	2.080	0.180	0.128	12.0	3.44	2.73	0.24	0.23	0.39	0.49	18.7	5.78	-	54.7	56.8	22.1
M 6x4.4	1.29	6.00	1.844	0.171	0.114	7.2	2.40	2.36	0.16	0.17	0.35	0.44	19.0	5.39	-	52.6	61.3	23.8

Chapter 514 LUMBER STRESSES & SIZES

Table 514-1. Allowable unit stress—structural lumber, psi.*

Allowable unit stresses listed are for normal loading conditions.

Species and commercial grade	Size classification	Allowable unit stresses in pounds per square inch						
		Extreme fiber in bending "F _b "		Tension parallel to grain "F _t "	Horizontal shear "F _v "	Compression perpendicular to grain "F _{c⊥} "	Compression parallel to grain "F _c "	Modulus of elasticity "E"
		Engineered uses (single)	Repetitive-member uses					
DOUGLAS FIR-LARCH (Surfaced dry or surfaced green. Used at 19% max. m.c.)								
Select Structural	2" to 4" thick	2100	2400	1200	95	385	1600	1,800,000
No. 1	2" to 4" wide	1750	2050	1050	95	385	1250	1,800,000
No. 2		1450	1650	850	95	385	1000	1,700,000
No. 3		800	925	475	95	385	600	1,500,000
Construction Standard	2" to 4" thick	1050	1200	625	95	385	1150	1,500,000
Utility	4" wide	600	675	350	95	385	925	1,500,000
Stud		275	325	175	95	385	600	1,500,000
		800	925	475	95	385	600	1,500,000
Select Structural	2" to 4" thick	1800	2050	1200	95	385	1400	1,800,000
No. 1	6" and wider	1500	1750	1000	95	385	1250	1,800,000
No. 2		1250	1450	825	95	385	1050	1,700,000
No. 3		725	850	475	95	385	675	1,500,000
Appearance	2" to 4" thick	1750	2050	1050	95	385	1500	1,800,000
	2" to 4" wide							
Appearance	2" to 4" thick	1500	1750	1000	95	385	1500	1,800,000
	6" and wider							
Select Structural	Beams and Stringers	1600	--	950	85	385	1100	1,600,000
No. 1		1350	--	675	85	385	925	1,600,000
Select Structural	Posts and Timbers	1500	--	1000	85	385	1200	1,600,000
No. 1		1200	--	825	85	385	1000	1,600,000
SOUTHERN PINE (Surfaced dry. Used at 19% max. m.c.)								
Select Structural		2100	2400	1250	90	405	1600	1,800,000
No. 1		1750	2000	1000	90	405	1250	1,800,000
No. 2	2" to 4" thick	1250	1450	725	75	345	850	1,400,000
No. 3		825	950	475	75	345	600	1,400,000
Construction Standard	2" to 4" wide	1050	1200	625	75	345	1150	1,400,000
Utility		600	700	350	75	345	925	1,400,000
Stud		275	325	175	75	345	600	1,400,000
		825	950	475	75	345	600	1,400,000
Select Structural	2" to 4" thick	1800	2050	1200	90	405	1400	1,800,000
No. 1		1500	1750	1000	90	405	1250	1,800,000
No. 2	6" and wider	1050	1200	700	75	345	700	1,400,000
No. 3		725	825	475	75	345	650	1,400,000

*This table is an abstract and does not include several factors affecting adjustments to design stresses.

Table 514-2. Lumber section properties.

NOMINAL B	DRESSED D	B	D	AREA A	INERTIA MOMENT I	SECTION MODULUS Z	SHEAR FACTOR 2BD/3	NOMINAL B	DRESSED D	B	D	AREA A	INERTIA MOMENT I	SECTION MODULUS Z	SHEAR FACTOR 2BD/3
1	x 2	3/4	x 1 1/2	1.13	0.21	0.28	0.75	3	x 8	2 1/2	x 7 1/2	18.13	79.39	21.90	12.09
	x 3		x 2 1/2	1.88	0.98	0.78	1.25		x 10		x 9 1/2	23.13	164.89	35.65	15.42
	x 4		x 3 1/2	2.63	2.68	1.53	1.75		x 12		x 11 1/2	28.13	296.63	52.73	18.76
	x 5		x 4 1/2	3.38	5.70	2.53	2.25		x 14		x 13 1/2	33.13	484.63	73.15	22.09
	x 6		x 5 1/2	4.13	10.40	3.78	2.75		x 16		x 15 1/2	38.13	738.87	96.90	25.43
	x 7		x 6 1/2	4.88	17.16	5.28	3.25								
1	x 8	3/4	x 7 1/2	5.44	23.82	6.57	3.63	3 1/2	x 2	3	x 1 1/2	4.50	0.84	1.13	3.00
	x 9		x 8 1/2	6.19	35.09	8.51	4.13		x 3		x 2 1/2	7.50	3.91	3.13	5.00
	x 10		x 9 1/2	6.94	49.47	10.70	4.63		x 4		x 3 1/2	10.50	10.72	6.13	7.00
	x 11		x 10 1/2	7.69	67.31	13.13	5.13		x 5		x 4 1/2	13.50	22.78	10.13	9.00
	x 12		x 11 1/2	8.44	88.99	15.82	5.63		x 6		x 5 1/2	16.50	41.59	15.13	11.01
	x 14		x 13 1/2	9.94	145.39	21.95	6.63	3 1/2	x 8	3	x 7 1/2	21.75	95.27	26.28	14.51
	x 16		x 15 1/2	11.44	221.66	29.07	7.63		x 10		x 9 1/2	27.75	197.86	42.78	18.51
1 1/2	x 2	1	x 1 1/2	1.50	0.28	0.38	1.00		x 12		x 11 1/2	33.75	355.96	63.28	22.51
	x 3		x 2 1/2	2.50	1.30	1.04	1.67		x 14		x 13 1/2	39.75	581.55	87.78	26.51
	x 4		x 3 1/2	3.50	3.57	2.04	2.33		x 16		x 15 1/2	45.75	886.64	116.28	30.52
	x 5		x 4 1/2	4.50	7.59	3.38	3.00	4	x 2	3 1/2	x 1 1/2	5.25	0.98	1.31	3.50
	x 6		x 5 1/2	5.50	13.86	5.04	3.67		x 3		x 2 1/2	8.75	4.56	3.65	5.84
	x 7		x 6 1/2	6.50	22.89	7.04	4.34		x 4		x 3 1/2	12.25	12.51	7.15	8.17
									x 5		x 4 1/2	15.75	26.58	11.81	10.51
									x 6		x 5 1/2	19.25	48.53	17.65	12.84
1 1/2	x 8	1	x 7 1/2	7.25	31.76	8.76	4.84	4	x 8	3 1/2	x 7 1/2	25.38	111.15	30.66	16.93
	x 9		x 8 1/2	8.25	46.79	11.34	5.50		x 10		x 9 1/2	32.38	230.84	49.91	21.59
	x 10		x 9 1/2	9.25	65.95	14.26	6.17		x 12		x 11 1/2	39.38	415.28	73.83	26.26
	x 11		x 10 1/2	10.25	89.74	17.51	6.84		x 14		x 13 1/2	46.38	678.48	102.41	30.93
	x 12		x 11 1/2	11.25	118.65	21.09	7.50		x 16		x 15 1/2	53.38	1034.42	135.66	35.60
	x 14		x 13 1/2	13.25	193.85	29.26	8.84	4 1/2	x 2	4	x 1 1/2	6.00	1.13	1.50	4.00
	x 16		x 15 1/2	15.25	295.55	38.76	10.17		x 3		x 2 1/2	10.00	5.21	4.17	6.67
1 1/2	x 2	1 1/2	x 1 1/2	1.88	0.35	0.47	1.25		x 4		x 3 1/2	14.00	14.29	8.17	9.34
	x 3		x 2 1/2	3.13	1.63	1.30	2.08		x 5		x 4 1/2	18.00	30.38	13.50	12.01
	x 4		x 3 1/2	4.38	4.47	2.55	2.92		x 6		x 5 1/2	22.00	55.46	20.17	14.67
	x 5		x 4 1/2	5.63	9.49	4.22	3.75	4 1/2	x 8	4	x 7 1/2	29.00	127.03	35.04	19.34
	x 6		x 5 1/2	6.88	17.33	6.30	4.59		x 10		x 9 1/2	37.00	263.82	57.04	24.68
	x 7		x 6 1/2	8.13	28.61	8.80	5.42		x 12		x 11 1/2	45.00	474.61	84.38	30.01
1 1/2	x 8	1 1/2	x 7 1/2	9.06	39.70	10.95	6.04		x 14		x 13 1/2	53.00	775.40	117.04	35.35
	x 9		x 8 1/2	10.31	58.49	14.18	6.88		x 16		x 15 1/2	61.00	1182.19	155.04	40.69
	x 10		x 9 1/2	11.56	82.44	17.83	7.71	6	x 6	5 1/2	x 5 1/2	30.25	76.26	27.73	20.18
	x 11		x 10 1/2	12.81	112.18	21.89	8.55		x 8		x 7 1/2	41.25	193.36	51.56	27.51
	x 12		x 11 1/2	14.06	148.32	26.37	9.38		x 10		x 9 1/2	52.25	392.96	82.73	34.85
	x 14		x 13 1/2	16.56	242.31	36.58	11.05		x 12		x 11 1/2	63.25	697.07	121.23	42.19
	x 16		x 15 1/2	19.06	369.44	48.45	12.71		x 14		x 13 1/2	74.25	1127.67	167.06	49.52
2	x 2	1 1/2	x 1 1/2	2.25	0.42	0.56	1.50		x 16		x 15 1/2	85.25	1706.78	220.23	56.86
	x 3		x 2 1/2	3.75	1.95	1.56	2.50	8	x 6	7 1/2	x 5 1/2	41.25	103.98	37.81	27.51
	x 4		x 3 1/2	5.25	5.36	3.06	3.50		x 8		x 7 1/2	56.25	263.67	70.31	37.52
	x 5		x 4 1/2	6.75	11.39	5.06	4.50		x 10		x 9 1/2	71.25	535.86	112.81	47.52
	x 6		x 5 1/2	8.25	20.80	7.56	5.50		x 12		x 11 1/2	86.25	950.55	165.31	57.53
2	x 8	1 1/2	x 7 1/2	10.88	47.63	13.14	7.25		x 14		x 13 1/2	101.25	1537.73	227.81	67.53
	x 10		x 9 1/2	13.88	98.93	21.39	9.25		x 16		x 15 1/2	116.25	2327.42	300.31	77.54
	x 12		x 11 1/2	16.88	177.98	31.64	11.26	10	x 6	9 1/2	x 5 1/2	52.25	131.71	47.90	34.85
	x 14		x 13 1/2	19.88	290.78	43.89	13.26		x 8		x 7 1/2	71.25	333.98	89.06	47.52
	x 16		x 15 1/2	22.88	443.32	58.14	15.26		x 10		x 9 1/2	90.25	678.76	142.90	60.20
2 1/2	x 2	2	x 1 1/2	3.00	0.56	0.75	2.00		x 12		x 11 1/2	109.25	1204.03	209.40	72.87
	x 3		x 2 1/2	5.00	2.60	2.08	3.33		x 14		x 13 1/2	128.25	1947.80	288.56	85.54
	x 4		x 3 1/2	7.00	7.15	4.08	4.67		x 16		x 15 1/2	147.25	2948.07	380.40	98.22
	x 5		x 4 1/2	9.00	15.19	6.75	6.00	12	x 6	12*	x 3/4	9.00	0.42	1.13	6.00
	x 6		x 5 1/2	11.00	27.73	10.08	7.34		x 8		x 1 1/2	18.00	3.38	4.50	12.01
2 1/2	x 8	2	x 7 1/2	14.50	63.51	17.52	9.67		x 10		x 2 1/2	30.00	15.63	12.50	20.01
	x 10		x 9 1/2	18.50	131.91	28.52	12.34		x 12		x 3 1/2	42.00	42.88	24.50	28.01
	x 12		x 11 1/2	22.50	237.30	42.19	15.01		x 14		x 4 1/2	54.00	91.13	40.50	36.02
	x 14		x 13 1/2	26.50	387.70	58.52	17.68		x 16		x 5 1/2	66.00	166.38	60.50	44.02
	x 16		x 15 1/2	30.50	591.10	77.52	20.34								
3	x 2	2 1/2	x 1 1/2	3.75	0.70	0.94	2.50								
	x 3		x 2 1/2	6.25	3.26	2.60	4.17								
	x 4		x 3 1/2	8.75	8.93	5.10	5.84								
	x 5		x 4 1/2	11.25	18.98	8.44	7.50								
	x 6		x 5 1/2	13.75	34.66	12.60	9.17								

*Full 12" wide.

